PB87-215372

Ecological Recovery After Reclamation of Toxic Spoils Left by Coal Surface Mining Phase 2. An Assessment of Environmental Changes Following Intensive Remedial Treatments

(U.S.) Tennessee Valley Authority, Norris

Prepared for

Environmental Protection Agency, Cincinnati, OH

Jul 87

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before comp

PB87-215372

1. REPORT NO. EPA/600/2-87/052
2.
4. TITLE AND SUBTITLE Ecological Recovery After Reclamation of Toxic Spoils Left by Coal Surface Mining, Phase II - An Assessment of Environmental Changes Following Intensive Remedial Treatments
5. REPORT DATE July 1987
6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Thomas G. Zarger, David H. Scanlon, Charles P. Nicholson Steven R. Brown, Lynn B. Starnes, and W. Douglas Harned
8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS

Tennessee Valley Authority
Division of Land and Economic Resources
Norris, Tennessee 37828

10. PROGRAM ELEMENT NO.
11. CONTRACT/GRANT NO. IAG No. D9 E721-DQ
12. SPONSORING AGENCY NAME AND ADDRESS

Hazardous Waste Engineering Research Laboratory
Office of Research and Development
U.S. Environmental Laboratory
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED Assessment July 1975-Sept. 1981
14. SPONSORING AGENCY CODE EPA-600/12
15. SUPPLEMENTARY NOTES
16. ABSTRACT

This study involves a selected watershed in which surface mining and unsuccessful reclamation efforts in the early 1970s resulted in adverse environmental impacts. Work on the east Tennessee problem mine sought to correct reclamation deficiencies by applying land stabilization treatments and then to evaluate their effectiveness by measuring the degree of recovery of the affected terrestrial and aquatic ecosystems. Conditions documented during the mining and reclamation, and those following restorative treatments provide a measure of ecological recovery. Evaluations on environmental effects cover vegetation, soils, water quality, aquatic macroinvertebrates, fish, small mammals, birds, and sedimentation.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Ecology Hydrology, Limnology Surface Mines Terrestrial Aquatic Soils	Ecological Effects Coal Tennessee Reclamation Water Quality Sedimentation	

18. DISTRIBUTION STATEMENT Release to the Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 143
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE 1a

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U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161

EPA/600/2-87/052
July 1987

ECOLOGICAL RECOVERY AFTER RECLAMATION OF TOXIC SPOILS LEFT BY COAL SURFACE MINING

Phase II

An Assessment of Environmental Changes Following Intensive Remedial Treatments

by

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealth with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environment and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report describes the initial terrestrial and aquatic ecosystems recovery of a coal surface mine following intensive reclamation of the site after reclamation efforts by the mine operator proved unsuccessful and resulted in adverse environmental impacts within a forestered watershed. This will be useful to biologists, engineers, or anyone else planning a reclamation project or concerned with the correction of problems associated with past or current mining. For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

Thomas R. Hauser, Director
Hazardous Waste Engineering
Research Laboratory

ABSTRACT

This study involves a selected watershed in which surface mining and unsuccessful reclamation efforts in the early 1970's resulted in adverse environmental impacts. Work on the east Tennessee problem mine sought to correct reclamation deficiencies by applying land stabilization treatments and then to evaluate their effectiveness by measuring the degree of recovery of the affected terrestrial and aquatic ecosystems. Conditions documented during the mining and reclamation, and those following restorative treatments, provide a measure of ecological recovery. Evaluations on environmental effects cover vegetation, soils, water quality, aquatic macroinvertebrates, fish, small mammals, birds, and sedimentation.

This report was submitted by the Tennessee Valley Authority, Office of Natural Resources and Economic Development, Division of Land and Economic Resources, in partial fulfillment of Energy Accomplishment Plan No. 81 BDQ under terms of Interagency Agreement No. D9 E721-DQ with the Environmental Protection Agency. Work was accomplished as of September 1, 1981.

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ACKNOWLEDGMENTS

Other TVA divisions assisting in various phases of this work included the Division of Services and Field Operations and the Division of Fossil and Hydro Power.

Coworkers in the Division of Land and Economic Resources are named for their successful and specialized help in conducting the study. They are: Joe B. Maddox, formerly Revegetation Specialist and now with the U.S. Department of Interior's Office of Surface Mining, for specific project planning and implementation of remedial reclamation treatments, and James E. Brown, formerly Revegetation Specialist and now with Auburn University, Department of Horticulture, for field documentation, data analysis, and progress reporting on vegetation establishment. Robert L. Curtis, Jr., designed the bird and small mammal sampling and James S. Pentecost, Jr., conducted much of the small mammal trapping.

Valuable assistance was provided by Gerald L. Vaughan, Department of Zoology, The University of Tennessee, who directed atomic absorption analyses of biological tissue samples.

The support of this project by the Office of Research and Development, U.S. Environmental Protection Agency, and the consultation provided by Ronald D. Hill are greatly appreciated.

SECTION 1

INTRODUCTION

The purpose of this investigation was to determine the rate of initial recovery of a damaged ecosystem in response to intensive remedial treatment of a problem surface mine. This study involved a forested watershed in which 162 hectares (ha) (400 acres (ac)) were disturbed by coal surface mining in the early 1970's. Mining and unsuccessful reclamation efforts resulted in adverse environmental impacts within a watershed that includes a city water supply reservoir.

An evaluation of the minesite in spring 1974 showed only 24 percent of the land surface stabilized and led to development and implementation of an intensive remedial land treatment plan (Zarger et al. 1979). Major study emphasis was on documenting the general mined land and stream quality conditions resulting from the problems created by mining and determining the rate of recovery of terrestrial and aquatic life after selected reclamation.

This report describes the status of initial ecological recovery following intensive remedial reclamation. Changes in terrestrial systems were evaluated in terms of vegetative development, soil chemistry, and population distributions of small mammals and birds. Aquatic systems were monitored for changes in water quality and macroinvertebrate and fish populations. Measurements of reservoir sedimentation rates provided an indicator of site stability achieved by reclamation performed on the mined area.

THE PROJECT AREA

The study area, Ollis Creek watershed, is located on land owned at the time by Koppers Company, Inc., 8 kilometers (km) (5 miles (mi)), north of Caryville and just east of Interstate 75 in Campbell County, Tennessee. Configuration of this mined area and its proximity to LaFollette, Tennessee, is shown in Figure 1.

Ollis Creek drains into a reservoir behind a concrete dam constructed in 1964 by the city of LaFollette. Storage water is released from this reservoir (Reservoir 2) to a smaller downstream impoundment (Reservoir 1) from which the city draws its needs. Upstream from Reservoir 2 the watershed drainage is 28 square kilometers (km^2) (11 square miles (mi^2)). This includes drainage from several small Ollis Creek tributaries that enter directly into the reservoir. Watershed elevations range from 415 meters (m) (1,360 feet (ft)) at the spillway crest to 762 m (2,500 ft) in the upper extremes.

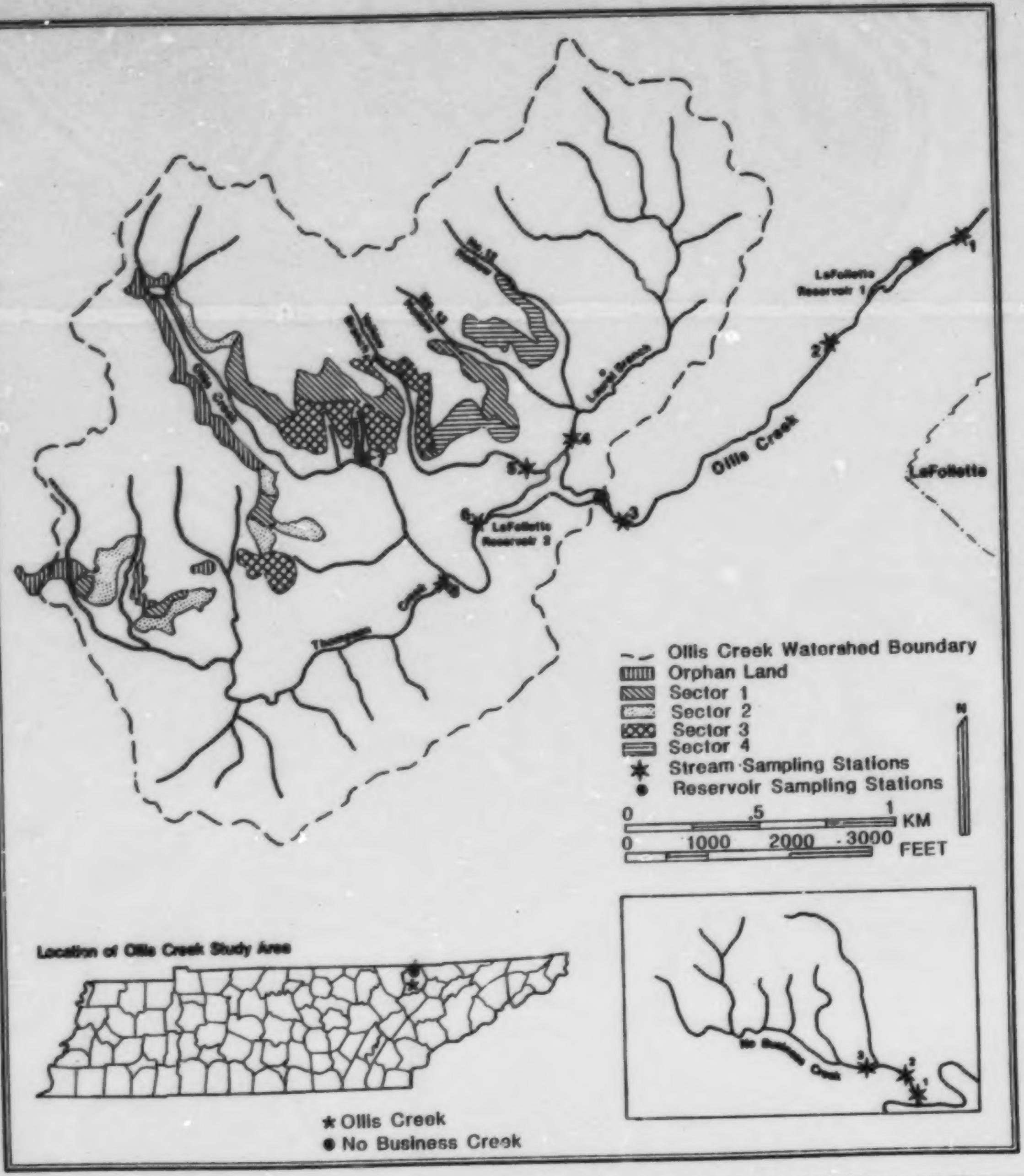
LaFollette Reservoir 1
Laurel Branch
Ollis Creek
LaFollette
LaFollette Reservoir 2
Thompson
Ollis Creek Watershed Boundary
▥ Orphan Land
▧ Sector 1
░ Sector 2
▦ Sector 3
▤ Sector 4
✱ Stream Sampling Stations
● Reservoir Sampling Stations
0 .5 1 KM
0 1000 2000 3000 FEET
N
Location of Ollis Creek Study Area
★ Ollis Creek
● No Business Creek
No Business Creek

Figure 1. Ollis Creek Watershed With Inset of No Business Creek Watershed and In-State Location

The watershed is heavily forested with oak-hickory being the predominant forest type. White and red oaks and hickory comprise the major hardwood sawtimber species, mostly in tree quality grades 2, 3, and structural. Other types present in the forest include yellow-poplar and Virginia pine. While logging has been active for many years, the forest is still relatively well stocked. Previous surface mining disturbed approximately 49 ha (120 ac). Most of this orphan land remains barren because of acid spoil conditions. There is also evidence of old deep mines along the main Ollis Creek drainage and on Thompson Creek, an arm of Ollis Creek.

The Ollis Creek area is bordered on the south by the Cumberland escarpment. Soils in the watershed are of either the Ramsey-Jefferson-Hartselle association or the Muskengum-Jefferson-Barbourville association, depending on the amount of clay, sand, and silt present (USDA 1959). The major soil type may be Muskengum stony fine sandy loam, steep to hilly phase, or Lehew fine sandy loam, steep to hilly phase. The majority of the area in the Ollis Creek watershed is underlain by the Slatestone group and may occur in conjunction with acid sandstones from the Crab Orchard and Gizzard groups (Wilson et al. 1956).

Coal reserves underlying the watershed include the Coal Creek seam, which was mined on the site of this study. Luther (1959) identified it as the most important in Campbell County, both from the standpoint of past production and reserves, and as having the largest known recoverable reserves of any seam in Claiborne County. The Keystone Coal Industry Manual (1972) further described the seam as ranging in thickness from 102 to 152 centimeters (cm) (40 to 60 inches (in.)), with most of the seam being between 102 and 122 cm (40 and 48 in.) thick. It usually carries a parting varying from knife-edge thickness to 10 cm (4 in.) slightly below the middle of the bed. The Slatestone overburden contains some strata low in pH and fertility and others with an excess of neutralizers and medium to high levels of nutrients except for phosphorus (Smith et al. 1976).

Area weather station data recorded at the LaFollette Water Treatment Plant, located on Ollis Creek, show the normal annual precipitation to range from 127 cm (50 in.) to 140 cm (55 in.). Yearly precipitation at the water plant exceeded these totals in most years from 1970, when stripping began, through 1975. Precipitation levels were near normal from 1976 through 1978.

Individual yearly totals were as follows:

Year	cm	in.	Year	cm	in.
1970	142	56	1976	119	47
1971	135	53	1977	142	56
1972	180	71	1978	129	51
1973	193	76	1979	165	65
1974	165	65	1980	104	41
1975	157	62			

Estimated mass inflow at Ollis Creek Reservoir, based on actual flow measurements of gaged area streams with similar characteristics, is estimated at over 11.4 million kiloliters (kl) (3 billion gallons (gal)) annually.

Surface mining conducted in the watershed between April 1970 and April 1972 was planned as a conventional mining and reclamation operation. It became the object of special study when the mine operator experienced difficulty in establishing vegetation on the graded spoils. Pyritic materials associated with the Coal Creek and Coal Creek rider seams became mixed with the overburden, leaving a hostile environment for plant growth and development. In a revegetation effort that continued through the 1973-1974 planting season, the operator planted more than 618,000 tree and shrub seedlings, sowed more than 8.3 metric tons (mt) (9.2 tons (t)) of grass and legume seeds, and applied 18.7 mt (20.6 t) of fertilizer. The repeated seeding and planting failed to provide the cover needed for offsite protection. Complete descriptions of mining and reclamation performed on the watershed and specific impacts of mining activities are presented in an earlier report (Zarger et al. 1979) covering this study.

REMEDIAL TREATMENT

Due to the serious problem of bare acid spoils and because it was unrealistic to request additional revegetation work from the operator, TVA, in fall 1974, assumed responsibility for needed remedial work. Selection of treatments that would effectively stabilize the surface without accelerating the rate of reservoir siltation or causing water quality problems was a major concern.

A 1974 evaluation showed some 39 ha (97 ac) to have adequate vegetative cover and 125 ha (308 ac) requiring treatment. Thus the mine was divided into four sectors (see Figure 1) of approximately equal land area--a control (Sector 1) with adequate vegetation and three sectors (Sectors 2, 3, and 4) comprising the poorly revegetated problem sites. Treatments selected and applied over 3 years included the spreading and disking of agricultural limestone to raise spoil pH, seeding with grasses and legumes to provide a protective ground cover, and planting trees and shrubs the following planting season (Table 1). This was considered the most effective way to complete the reclamation with minimum damage to the water resource.

Specifically, cultural practices to establish herbaceous ground cover consisted of both fall and spring treatments. Fall treatments involved liming at the rate of 22.4 mt/ha (10 t/ac) and disking; fertilizing with a 6-12-12 fertilizer at 224 kilograms/hectare (kg/ha) (200 pounds/acre (lb/ac)); and seeding a mixture of half rye, or barley, and half Kentucky-31 fescue at 67 kg/ha (60 lb/ac). In the following spring the same area was overseeded with a mixture of Kentucky-31 fescue, sericea lespedeza, and weeping lovegrass at 34, 34, and 2 kg/ha (30, 30, and 2 lb/ac), respectively. Additionally, a 6-12-12 fertilizer was broadcast at 224 kg/ha (200 lb/ac).

TABLE 1. CONDITION, AREA, AND VEGETATIVE TREATMENTS BY SECTOR

Sector	Condition (1975)	Area		Ground cover treatments	Tree and shrub seedlings planted	
		ha	ac	Season*	No. (M)	Season
1	Good	39.0	97	None	None	-
2	Poor	40.5	100	F74-S75	97†	75-76
3	Poor	40.5	100	F75-S76	82‡	76-77
4	Poor	43.7	108	F76-S77	108#	77-78

* F=fall, S=spring.

† Virginia pine (57 M), autumn-olive (40 M).

‡ Autumn-olive (42 M), loblolly pine (35 M), European alder (5 M).

# Virginia pine (55 M), autumn-olive (40 M), black locust (13 M).

SECTION 2

TERRESTRIAL SYSTEMS

VEGETATION

Vegetation surveys were conducted annually from 1975 to 1980 to provide data for measuring changes in herbaceous and woody plant cover following application of prescribed remedial reclamation treatments. The establishment of naturally seeded vegetation on treated and untreated areas of the mined site was of particular interest.

Methods

A TVA field survey manual (McCarthy 1975) provided guidelines on vegetative survey methodology and sampling. Baseline data on vegetation were collected in fall 1975 by systematically selecting 2-square-meter (m^2) (21.5 ft^2) plots within each of the four sectors (Table 1) to provide coverage of approximately one plot per acre. Later, permanent plots of the same size were established within representative areas of each sector. Recovery monitoring data were then taken for 5 years, 1976-1980, on permanent plots. Measurements included: (1) tree and shrub species growing on plots, a stem count of each, their basal diameter, and total height and (2) grass and legume species, their height, and ground cover percentage. Additional data were collected on spoil pH and percentage of natural and reclamation vegetation present.

Results and Discussion

The percentage of vegetative ground cover, both natural and that resulting from reclamation efforts, is summarized by sectors in Table 2. Sector 1 received no remedial treatments because it was characterized as revegetated in 1974. Although the percentage of natural vegetation there doubled during the period of evaluation, reclamation vegetation also increased and covers most of the sector. Remedial reclamation resulted in dramatic increases in cover on Sectors 2, 3 and 4. In Sector 2 reclamation vegetation became heavily established and appeared to compete successfully with natural species. In contrast, on Sectors 3 and 4, reclamation vegetation only accounted for about 40 percent of the area and natural species invaded on 30 percent. Apparently the liming and disking prepared hospitable sites for seed germination and establishment of native pioneer species.

Over 75 species of herbaceous and woody plants (listed with scientific names in Appendix A-1) were found on the study area from 1975 to 1980. The plants fell into five categories: grasses, 10 species, plus several *Panicum* spp.; legumes, 9 species; composites, 14 species; trees and shrubs, 13 and 4 respectively; and miscellaneous, 25 species. The species community changed greatly during the 5 years. As evidence of ecological change, 22 species occurring in 1975 were gone by 1980, while 21 other species had become established since 1975.

TABLE 2. FIVE-YEAR CHANGE IN VEGETATIVE GROUND COVER ON THE MINESITE

	Sector							
	1		2*		3		4	
Source of vegetation	1975	1980	1975	1980	1975	1980	1975	1980
	Percent							
Natural	5	11	8	13	7	30	3	30
Reclamation	58	78	29	70	8	42	19	40
TOTAL	62	89	37	83	15	72	22	70

* Partial treatment (limed at 22.4 mt/ha (10 t/ac) fertilized, disked, and seeded to grasses and legumes) applied in the fall 1974 to spring 1975 season, or prior to initiation of "Ecological Recovery" study.

Herbaceous species--Development of herbaceous ground cover over 5 years on the four mine sectors is shown in Table 3. Legumes produced the largest percentage increase over the period, although grasses were the predominant cover in all sectors except Sector 2. Composites increased in percentage of cover on all sectors except Sector 3, which was the most acidic. On Sector 3 miscellaneous acid-tolerant species increased to provide 10 percent of the sector cover. Legumes composed primarily of aggressive reclamation species will likely continue to increase in ground cover percentage, particularly on Sectors 3 and 4, which were seeded in 1976 and 1977.

Grass species changes in occurrence, height, and composition over the 5-year period are presented in Table 4. Results indicated a greater occurrence of grass species in 1980 and reduced composition percentages since 1975. Four species not found in 1975, crabgrass, poverty oatgrass, orchardgrass, and redtop grass occurred in 1980, while perennial ryegrass was no longer evident. The occurrence and composition of grass species in the four sectors is shown in Appendix A-2. Sector 1, which received no remedial treatment, had only five grass species in 1980, while Sectors 2, 3, and 4 had eight to nine species and better balance in cover composition. Kentucky-31 fescue and weeping lovegrass, primary reclamation species, occurred on all mine sectors, and these species combined provided from 28 to 47 percent of total ground cover on the sectors in 1980.

The development of native grass species on Ollis Creek is similar to that recorded by Riley (1977) in studies of ecological recovery of coal strip mines in southeastern Ohio and by Byrnes and Miller (1969) in southern Indiana. Broomsedge was the most prevalent native grass occurring over all mine sectors on Ollis Creek, and this species also was dominant in the ground cover found on both the Ohio and Indiana minesites. Poverty oatgrass, which was prominent in Ohio mine ecosystem recovery 8 years after spoil regrading, also was found to have invaded the three treatment sectors at Ollis Creek between 1975 and 1980. Panic grass was a primary companion species of broomsedge on the Indiana study sites, and it was also found on all Ollis Creek sectors, although its development appeared to be hindered by competition with reclamation species except on Sector 4. Graham (1947), from observations of natural ecosystem development on disturbed sites in southeastern Ohio, noted that grasses were the predominant cover at the 5-year stage of development. The invasion of native grasses on Ollis Creek over approximately 5 to 8 years indicate a similar developmental stage, although heavy reclamation seedings of legumes have reduced grass cover.

TABLE 3. HERBACEOUS GROUND COVER BY SPECIES CATEGORY AND SECTOR

	Sector							
	1		2*		3		4	
Source of Vegetation	1975	1980	1975	1980	1975	1980	1975	1980
	Percent							
Grasses	52	45	28	32	10	42	20	33
Legumes	7	36	4	42	1	19	0	20
Composites	1	5	1	4	1	1	1	11
Miscellaneous†	2	3	4	5	3	10	1	6
TOTAL	62	89	37	83	15	72	22	70

* Partial remedial treatment prior to initiation of the study.

† Characterized as miscellaneous because of the large number of species involved and their infrequent occurrence.

Legumes showed dramatic increases in occurrence and percent composition of minesite ground cover over the 5-year evaluation period (Table 5). The extensive seeding of Kobe, Korean, and sericea lespedeza by the mine operator and additional sericea in the remedial treatment resulted in progressive increases of leguminous cover, and these three species provided 38 percent of total study site ground cover in 1980. Legumes invading during the 5 years were beggar-lice, bushclover, partridge-pea, and yellow sweetclover, although they provided minimal ground cover on the site. The distribution of legumes over the four mine sectors was relatively well balanced (Appendix A-3). Sericea lespedeza occurred on 50 to 75 percent of the sample plots in 1980. Since the species develops slowly and becomes more competitive, it is likely that the percent composition of sericea will continue to increase. The advantage of vigorous legume growth is the fixation of nitrogen in the soil and improvements

TABLE 4. DEVELOPMENT OF GRASS SPECIES ON THE MINESITE

Species	Occurrence* (%)		Mean height (cm)		Composition† (%)	
	1975	1980	1975	1980	1975	1980
Barnyard grass	‡	2	60	46	‡	‡
Broomsedge	10	28	2	76	4	7
Crabgrass	-	1	-	22	-	‡
Fescue, K-31	50	68	18	40	60	26
Lovegrass, weeping	13	24	18	67	12	8
Millet, foxtail	‡	1	15	95	‡	‡
Oatgrass, poverty	-	7	-	15	-	‡
Orchardgrass	-	12	-	29	-	2
Panic grass	8	7	25	33	4	1
Redtop grass	-	1	-	152	-	‡
Ryegrass, perennial	‡	-	20	-	‡	-
Switchgrass	1	4	24	78	1	1

* The number of plots on which a species occurred divided by the total number sampled.

† The amount of ground cover provided by a single species related to total amount of ground cover.

‡ Less than 0.6 percent.

TABLE 5. DEVELOPMENT OF LEGUME SPECIES ON THE MINESITE

Species	Occurrence* (%)		Mean height (cm)		Composition† (%)	
	1975	1980	1975	1980	1975	1980
Beggar-lice	-	1	-	110	-	‡
Bushclover	-	3	-	28	-	‡
Clover, red	‡	-	8	-	‡	-
Lespedeza, Kobe	‡	15	23	22	‡	7
Lespedeza, Korean	2	8	15	22	1	3
Lespedeza, sericea	17	66	53	93	7	28
Partridge pea	-	2	-	42	-	‡
Sweetclover, yellow	-	2	-	26	-	‡
Sicklepod	‡	-	25	-	‡	-

* The number of plots on which a species occurred divided by the total number sampled.

† The amount of ground cover provided by a single species related to total amount of ground cover.

‡ Less than 0.6 percent.

in site amelioration at Ollis Creek should become evident in the next 10 years. The companion plants that can compete with sericea will benefit from the increased nitrogen levels.

Composite species have provided diversity and a measure of ecological recovery on the Ollis Creek mine, although their occurrence and percent composition have been relatively limited (Table 6). Three species--hawkweed, Joe-pye-weed, and Spanish needle--have invaded since 1975, while dandelion, field daisy, fleabane, and wild lettuce were no longer found in 1980. Occurrence and composition by sectors (Appendix A-4) revealed that only the asters were found on all four sectors. Goldenrod was well represented except on Sector 3, where acidity appeared to limit the invasion of composites. In southern Indiana, Byrnes and Miller (1969) also found aster and goldenrod to occur frequently in natural invasion of a wide range of minesite types. They noted that aster and goldenrod would increase with time, and the data from Ollis Creek support this. On Sector 1, which had good vegetation established over 5 years, aster and goldenrod provided 6 percent of ground cover in 1980, compared with approximately 1 percent in 1975. The remedially treated sectors, and especially Sector 4, should have increased frequency of these species if they follow the trend of Sector 1 as expected. Other composite species will likely continue to be transitional, invading and dying out, until a shrub and tree canopy forms to greatly reduce the occurrence of species in this family.

Miscellaneous plants included a widely diverse group of 25 species in many families that generally occurred infrequently and comprised only a small percentage of total ground cover (Table 7). Rapid ecological change was particularly evident in this category, where 13 species, including ferns, club moss, fungi, mosses, lichen, fireweed, pokeberry, knotweed, red sorrel, purslane, and loosestrife, recorded in 1975, were no longer in evidence by 1980. Invading species over the 5 years included cinquefoil, mint, slender gerardia, violet, honeysuckle, and blueberry. Distribution by mine sector, shown in Appendix A-5, reveals that the number of miscellaneous species in Sector 1 dropped from 10 to 2 during the 5-year period. Sector 4, with nine species in 1980, was the only sector to show an increase during the period. The disking and liming of Sectors 3 and 4 were likely responsible for the increase in miscellaneous species, which comprised over 10 percent of total cover on the two sectors. Predominant species providing cover were blackberry and nutsedge. Greenbrier was also fairly common on the Ollis Creek site, although it had died out on Sectors 1 and 3 after 1975. Surveys of natural invasion of 17 mine sites in southern Indiana showed blackberry, greenbrier, and nutsedge all to be very frequent invaders (Byrnes and Miller 1969). Blackberry was also the most prominent shrub found on 20 naturally invaded minesites surveyed in Pennsylvania (Bramble and Ashley 1955). Increased development of blackberry on Ollis Creek is expected over the next 5 to 10 years or until a closing canopy of trees and shrubs begins to shade out the species. Other miscellaneous species will continue to provide diversity and wildlife benefits but are not likely to add appreciably to total ground cover.

Over the 5 years of evaluation, the overall diversity of herbaceous species has diminished by two species. By sectors and categories, the numbers of species in 1975 and 1980 are summarized in Table 8.

TABLE 6. DEVELOPMENT OF COMPOSITE SPECIES ON THE MINESITE

Species	Occurrence* (%)		Mean height (cm)		Composition† (%)	
	1975	1980	1975	1980	1975	1980
Aster	4	26	37	45	1	3
Coreopsis	‡	1	20	109	‡	‡
Daisy, field	1	-	27	-	‡	-
Dandelion	‡	-	14	-	‡	-
Fleabane	‡	-	56	-	‡	-
Goldenrod	‡	16	76	79	‡	3
Hawkweed	-	2	-	12	‡	‡
Joe-pye-weed	-	1	-	159	-	‡
Small ragwort	‡	1	25	9	‡	‡
Spanish needle	-	2	-	41	-	‡
White snakeroot	‡	3	10	109	‡	‡
Wild lettuce	‡	-	7	-	‡	‡

* The number of plots on which a species occurred divided by the total number sampled.

† The amount of ground cover provided by a single species related to total ground cover.

‡ Less than 0.6 percent.

TABLE 7. DEVELOPMENT OF MISCELLANEOUS SPECIES ON THE MINESITE

Species	Occurrence* (%)		Mean height (cm)		Composition† (%)	
	1975	1980	1975	1980	1975	1980
Blackberries	2	10	34	86	‡	2
Blueberries	-	1	-	26	-	‡
Buckwheat: Knotweed	‡	-	5	-	‡	-
Smartweed, Penn	2	1	29	17	1	‡
Sorrell, red	1	-	3	-	‡	-
Cattails	2	1	64	130	2	‡
Cinquefoil	-	1	-	7	-	‡
Ferns and fern allies	‡	-	10	-	‡	-
Fireweed	1	-	26	-	‡	-
Fungi: Puffball and mushrooms	‡	-	6	-	‡	-
Greenbrier	3	2	20	40	‡	‡
Honeysuckle	-	1	-	20	-	‡
Lichen, fructicose	1	-	1	-	‡	-
Loosestrife, whorled	‡	-	25	-	‡	-
Mint	-	1	-	35	-	‡
Moss	4	-	2	-	1	-
Pokeberry	1	-	70	-	‡	-
Purslane, common	‡	-	23	-	‡	-
Sedges: Nutsedge	2	10	7	71	‡	4
Bulrush	2	1	94	68	2	‡
Slender gerardia	-	1	-	14	-	‡
Violet	-	2	-	5	-	‡

* The number of plots on which a species occurred divided by the total number sampled.

† The amount of ground cover provided by a single species related to total ground cover.

‡ Less than 0.6 percent.

TABLE 8. FIVE-YEAR CHANGE IN THE NUMBER OF HERBACEOUS SPECIES BY SECTOR

	Sector							
	1		2		3		4	
Source of vegetation	75	80	75	80	75	80	75	80
	Species No.							
Grasses	6	5	6	9	6	9	4	8
Legumes	2	4	3	5	2	3	1	6
Composites	4	5	4	4	4	2	4	7
Miscellaneous	10	2	12	6	15	5	8	9
Total	22	16	25	24	27	19	17	30

Sector 1, undisturbed during the evaluation, had a net loss of six species during the period. Sector 2, first to be renovated, experienced a trend in species reduction. The acidity of Sector 3 could have been responsible for the species losses incurred there. The most recent remedial treatment applied to Sector 4 provided a stimulus to species invasion, and that effect was evident in the 1980 count. Although many variables are involved in this type study, the trend toward diminishing diversity with age and competition from aggressive species was apparent early on the Ollis Creek site.

Trees and shrubs--The number and distribution of forest tree and wildlife shrub seedlings found growing on the mine in 1975 and 1980, shown in Table 9, were the result of both natural invasion and reclamation planting.

TABLE 9. FIVE-YEAR CHANGE IN DENSITY AND STOCKING OF WOODY PLANTS

		Sector			
		1	2	3	4
Stems per ha*	(1975)	1,307	1,494	2,272	2,061
	(1980)	2,875	3,727	5,109	4,474
Stocking percent‡	(1975)	21	16	26	23
	(1980)	35	42	57	39

* Planting at 1.8 x 1.8 m (6 x 6 ft) approximates 3,000 seedlings per ha (1,210 per ac).

‡ Number of plots on which one or more woody plants occurred divided by the total number sampled times 100.

Planting success for reclamation purposes is sometimes defined as being the establishment of at least 1,500 woody stems per ha (600 per ac) occurring on more than 50 percent of the area (50 percent stocking). Since the number of living stems far exceeded the minimum 1,500 stems on all four sectors, the limiting factor here is the achievement of balanced distribution. However, the 1980 evaluation revealed persistence of uneven distribution; seedlings were dense on some areas, while on others no seedlings were present. Although stocking percentage greatly increased on all sectors, only Sector 3 reached the success standard. Competition from more dense herbaceous cover on Sectors 1 and 2 may have limited the establishment of woody plants. High variability of spoils on Sector 4 resulted in dense herbaceous cover on some areas, while other areas were highly toxic; 16 percent of the plots sampled there were devoid of vegetation.

Of 17 tree and shrub species (Table 10), loblolly pine and black locust, which were most abundant in 1975, were overtaken by Virginia pine, autumn-olive, and red maple. Three natural invading species and one planted exotic were added between 1975 and 1980, while two reclamation species were no longer found on the plots.

Sectors with the most ground cover had fewer trees and shrubs per ha than sectors with less ground cover. For example, Sector 1 (control) had 89 percent herbaceous ground cover and only 2,875 stems per ha and 35 percent stocking, while Sector 3 had only 72 percent ground cover, but 5,109 stems per ha and 57 percent stocking.

Naturally seeded trees and shrubs accounted for 41 percent of the average stems per ha in 1980, which was an appreciable increase over the 26 percent recorded in 1975, considering that 287,000 trees and shrubs were planted during remedial reclamation of the area. The increased numbers of native woody plants on remedial treatment areas at Ollis Creek were first observed in the 1977 evaluation (Starnes et al. 1978). Native plant increases were attributed to the liming and disking, which improved seedbed characteristics and to the incorporated fertilizer treatment, which promoted root growth and reduced seedling losses from frost heaving.

Red maple was the predominant native woody species invading the Ollis Creek minesite. Other common species from the residual forest that invaded in good number were sourwood, sweetgum, shortleaf pine, yellow-poplar, and sumac, in that order. All of these were recorded in 1975 and 1980. Black cherry, blackgum, and black willow invaded after 1975. In comparing woody plant species, which invaded Ollis Creek with those found in the Ohio (Riley 1977), Pennsylvania (Bramble and Ashley 1955), and Indiana (Byrnes and Miller 1969) ecosystem studies, it was noted that red maple occurred very frequently on all minesites. Black cherry invaded mines more heavily in Ohio and Indiana than in Tennessee. Yellow-poplar was more common in Ohio and Tennessee than in Indiana, while sumac was more prevalent on Tennessee and Indiana mines. Sourwood and sweetgum are more southerly species and were not found on Ohio or Indiana sites. Persimmon and sassafras were found to be numerous on Indiana sites, while they were not observed on the Ollis Creek site. A possible explanation is that both are heavy-seeded species, which require transport by birds or animals. As the wildlife habitat improves on the site, it is probable

TABLE 10. CHANGES IN STEM DENSITY AND STOCKING OF INDIVIDUAL SPECIES

Tree and shrub species	Stems per ha 1975	 1980	Stocking percent 1975	 1980
Alder, European (R)*	-	140	-	2.2
Autumn-olive (R)	79	587	1.6	8.4
Blackgum (N)†	-	56	-	0.6
Cherry, black (N)	-	56	-	1.1
Filbert (R)	11	-	0.2	0.0
Locust, black (R)	439	307	6.8	5.6
Maple, red (N)	23	670	0.5	7.8
Oak, sawtooth (R)	45	-	0.5	0.0
Pine, loblolly (R)	462	84	7.5	1.7
Pine, shortleaf (N)	248	140	3.7	2.8
Pine, Virginia (R)	293	1,006	2.7	13.4
Shrub lespedeza (R)	11	251	0.2	2.2
Sourwood (N)	102	363	1.8	3.4
Sumac (N)	45	56	0.2	0.6
Sweetgum (N)	11	196	0.2	3.4
Yellow-poplar (N)	45	84	0.5	1.7
Willow, black (N)	-	56	-	1.1

* (R)=reclamation planting.

† (N)=natural seeding.

that persimmon and sassafras will become evident. Tree species other than red maple were not common to Tennessee and Pennsylvania study sites, probably because of differences in climatic conditions.

Heights of woody plants growing on the minesite in the fall of 1975 and 1980 are compared by species in Table 11. The early planted loblolly pine and black locust showed dominant height growth, but naturally occurring species like yellow-poplar and sweetgum showed evidence of becoming more prominent in stand structure.

Summary

The approximately 162 ha (400 ac) comprising the minesite has developed a much improved total vegetative cover over the course of the evaluation. A 1974 reconnaisance survey to determine reclamation problems on the site showed that only 24 percent of the land surface was revegetated. The baseline survey in 1975, following limited remedial reclamation, recorded 33 percent cover; and 5 years later, with all problem areas treated, the overall vegetative cover exceeded 78 percent. Ground cover on the untreated sector reached 89 percent, while Sectors 2, 3, and 4 contained 83, 72, and 70 percent respectively. In terms of the origin of ground cover vegetation on the sectors, almost 30 percent was from natural seeding on Sectors 3 and 4, while Sectors 1 and 2 had only approximately 12 percent natural vegetation.

Ecological diversity and change were indicated by over 55 species of herbaceous and woody plants found in 1980, which included 21 species not recorded in 1975. Also 22 species found in 1975 were not tallied in 1980. Predominant herbaceous species were those seeded or planted in remedial revegetation efforts. Kentucky-31 fescue comprised 26 percent of the herbaceous vegetative cover; weeping lovegrass, 8 percent; and sericea lespedeza, 28 percent. Broomsedge was the predominant native species, with 7 percent cover.

Virginia pine, autumn-olive, and natural seeded red maple were the predominant woody plants in 1980, replacing loblolly pine and black locust. The numbers of woody plants were greater on sectors with lesser amounts of herbaceous ground cover. Tree and shrub seedlings established per ha exceeded the minimum numbers needed for reclamation success. However, they were not evenly distributed over the minesite, and only Sector 3 provided a successful stocking of more than 50 percent.

Remedial reclamation treatments have resulted in generally successful vegetation on a difficult site. A reasonably good mix of vegetative types has developed over a 5-year period. A substantial legume component is present on all mine sectors and it should contribute to further stabilize and ameliorate the site during development of the forest ecosystem.

SPOIL CHEMISTRY

Core samples 10-15 cm (4-6 in.) deep were taken on each plot and pH was determined in the laboratory on <60 mesh samples (1:1 soil to water ratio on a weight basis). A summary of spoil pH values recorded in the fall of 1975 and 1980 are shown in Table 12.

TABLE 11. TREE AND SHRUB HEIGHTS IN 1975 AND 1980

Species	Mean height (m) 1975	Mean height (m) 1980	Height range (m) 1980
Alder, European	-	1.3	0.8-2.0
Autumn-olive	1.6	1.4	0.6-3.9
Blackgum	-	1.6	1.6-1.6
Cherry, black	-	0.6	0.5-0.6
Filbert	0.2	0.0	-
Locust, black	1.2	3.1	1.4-7.6
Maple, red	0.2	0.3	0.1-1.9
Oak, sawtooth	0.4	0.0	-
Pine, loblolly	1.0	2.5	0.1-7.4
Pine, shortleaf	0.4	0.9	0.3-1.7
Pine, Virginia	0.5	1.1	0.1-3.9
Shrub lespedeza	1.5	1.2	0.4-3.1
Sourwood	0.3	0.3	0.1-0.8
Sumac	0.1	1.1	1.1-1.1
Sweetgum	0.2	1.9	0.1-3.4
Yellow-poplar	0.1	2.1	0.8-4.4
Willow, black	-	2.2	1.0-3.4

TABLE 12. CHANGES IN SPOIL pH BY MINE SECTOR

	Sector			
	1	2	3	4
	-pH-			
1975 Mean	4.9	3.8	3.5	3.6
Range	3.0-7.2	2.8-6.1	2.9-4.8	2.6-5.1
1980 Mean	4.6	4.4	3.9	4.2
Range	2.8-6.9	2.7-6.2	2.7-6.6	2.1-6.4

The mean pH value for Sector 1, which received no lime application, dropped slightly during the evaluation period, while pH values of the three limed sectors increased. Sector 3, with a pH of 3.9 was the most acidic, and this was reflected in vegetative responses discussed in the previous section. As shown in the range of pH values, all four sectors continued to have some areas with highly acid spoils. Sector 1 had only 1 sample plot with a pH less than 3.0, while Sector 2 contained 5 such plots, Sector 3 had 11, and Sector 4 had 6.

Correlation of presence or absence of satisfactory vegetative cover (greater than 60 percent) on sample plots with corresponding pH values revealed that only 22 percent of the plots with pH values less than 3.0 were adequately vegetated. However, on plots with pH values from 3.0 to 3.5, it was found that 69 percent were satisfactorily vegetated. For establishment and growth of vegetation on the Ollis Creek area, it appears that a pH of 3.0 is the marginal value below which success is very unlikely.

Other examinations in spoil chemistry in this study were deferred because separate studies by Smith et al. (1976) and Ott (1978) contained many chemical analyses of the Ollis Creek mine spoils and highwall materials. These separate investigations were conducted to determine overburden characteristics and the effects of many spoil variables on the establishment of vegetation.

Samples in Ott's (1978) study were analyzed for pH, calcium, magnesium, potassium, phosphorus, iron, aluminum, manganese, zinc, compaction, moisture content, surface temperature, and color. Analyses indicated all spoils contained low concentrations of nutrients. Potassium, phosphorus, manganese, and zinc were in the deficiency range of most plants. The solubility of aluminum and iron increased with low pH, thus increasing the probability of their interactions with and decreased availability of other plant nutrients. Nonvegetated areas had lower values than vegetated areas for pH and potassium, and higher values for exchangeable magnesium, iron, and aluminum.

Smith et al. (1976) included analyses of overburden and minesoil at Ollis Creek. They concluded that carbon-rich shale in the 2.4 m (8 ft) of overburden immediately above the coal was highly toxic and largely responsible for the low pH levels and nutrient deficiencies found in minesoil samples. Characteristics of this carbon-rich shale and its effect on plant growth were studied by McFee et al. (1981) in Indiana. The black shales from southwestern Indiana used in the study occurred in close proximity to the coal seam and had pH values of 2.7 to 3.7, similar to the Ollis Creek shale. Results of chemical tests showed the shale to have excessively high levels of soluble salts, aluminum, boron, and sulfur, and a high potential acidity. Both greenhouse and field container tests resulted in very limited plant growth on the shale. The conclusion was that shale of this type is totally unsuitable for plant growth. Incorporation of similar shale materials in the top layer of graded spoils on the Ollis Creek study area was likely responsible for the revegetation problems encountered on the site.

BIRD AND SMALL MAMMAL POPULATIONS

The Ollis Creek mine provided an opportunity to study the response of small mammals and birds to intensive reclamation treatments. Very few studies (Willson 1974, Roth 1976) have been reported in the United States that quantify bird population successional patterns on early successional habitats such as coal strip mined areas. Likewise only a few studies (Verts 1959, Decapita and Brookout 1975, Sly 1976) of small mammal succession have been made on lands stripped for coal.

In this study birds were censused on permanent plots during the summer breeding season (late May through June) and during the winter (late December through February). Bird censuses were conducted from the summer of 1976 through the winter of 1981. Mammals were sampled by snap-trapping two permanent lines in each sector during June and October-November from 1976 to 1980.

Methods

Censusing--Birds were censused on 55 plots, each approximately 0.34 ha (.83 ac), located among the four sectors of the mine (Figure 1). Of the 55 plots, 15 were located in Sector 1, 14 in Sector 2, 13 in Sector 3, and 11 in Sector 4 (Table 1).

Plots were censused during a 4-minute period by walking lengthwise through the plot and recording all birds seen or heard. Four replications were made on each plot. The results of each winter census were averaged for each plot, and the mean was then used as a density figure. Density was calculated from summer census data by averaging census results of territorial species only. A species observed at least twice on a plot, or whose nest was found on the plot, was considered to be territorial, with its territory including at least a portion of the plot.

Small mammals were trapped on each of the four sectors, in two permanent traplines per sector. Each trapline contained 19 stations, 10 m (32.8 ft) apart, with two Museum Special snap traps at each station. Traps were baited with a mixture of peanut butter and rolled oats. During each summer and fall trapping session, traps were operated for 10 consecutive nights, giving a total of 760 trap nights per sector, or 3,040 trap nights on the combined area.

Data analysis--Between-year and between-sector differences in bird populations were analyzed by analysis of variance and Pearson product-moment correlation tests. Attempts were also made to define bird population changes in relation to vegetation changes. Vegetation data were gathered separately from bird population studies and recoded for use here (Table 13). Vegetation was measured at permanent grid points, some of which defined boundaries of bird census plots. In order to relate the vegetation data to a particular bird plot, the herbaceous vegetation information measured at each end of the bird plot was averaged and then assigned to the plot. Woody vegetation data were obtained by summing the number of stems measured in the vegetation plot at each end of the bird census plot. Vegetation data were available for 11 plots in Sector 1, all the plots in Sector 2, 12 plots in Sector 3, and all the plots in Sector 4. Relationships between bird population and vegetation parameters were analyzed by correlation and multiple regression procedures. Statistical tests yielding a probability of ≤ 0.05 were considered significant.

Scientific names of birds and mammals are listed in Appendix B-1.

TABLE 13. ABBREVIATIONS AND DESCRIPTIONS OF VEGETATION VARIABLES USED IN ANALYZING BIRD HABITAT PREFERENCES

Variable	Description
TOTCOV	Proportion of plot covered with herbaceous vegetation
NATCOV	% of TOTCOV made up of naturally occurring (i.e., volunteer) herbaceous vegetation
REVCOV	% of TOTCOV made up of revegetation materials
HERBDIV	Number of different herb species on plot
HERBHT	Weighted average height of herbaceous vegetation $= \frac{\sum_{\text{spp. } A \rightarrow j} (\text{ht})(\% \text{ cover})}{100}$
HERBHC	Index of herbaceous vegetation volume = HERBHT x TOTCOV/100
GRAMCOV	% of TOTCOV made up at graminiferous plants
FORBCOV	% of TOTCOV made up of forbs
TOTWOOD	Total number of woody stems on plot
WOODA	Number of woody stems <100 cm tall
WOODB	Number of woody stems 101-200 cm tall
WOODC	Number of woody stems 201-300 cm tall
WOODD	Number of woody stems >300 cm tall

Results

Breeding bird populations--The breeding bird population showed major changes between years and between sectors (Appendices B-2 through B-5). When all sectors were combined, the bird population was highest in 1980 and lowest in 1977 (Table 14).

Sector 1 had the highest bird population in the years 1976 to 1978, but the Sector 1 population was equaled or slightly exceeded by other sectors in 1979 and 1980 (Figure 2). The total breeding population (TOTAL) differed significantly between sectors in 1976. There was less difference in succeeding years. During 1976 the tufted titmouse and field sparrow differed significantly between sectors, with the titmouse most abundant in Sector 2 and the field sparrow most abundant in Sector 1. The indigo bunting was the only species showing a significant population difference in 1977, and it was most abundant in Sector 1. There was no significant between-sector difference in any species in 1978. In 1979 significant between-sector differences were found in the prairie warbler, red-winged blackbird, indigo bunting, and field sparrow. During 1980 the only species showing a significant between-sector difference was the prairie warbler, which was most abundant in Sector 3.

When broken down by sectors, several species also showed significant trends of increasing or decreasing density during the 5-year study period. In Sector 1 the yellow-breasted chat showed a significant positive trend, while the American goldfinch significantly decreased. In Sector 2 the golden-winged warbler, indigo bunting, field sparrow, and TOTAL significantly increased, while the tufted titmouse and prairie warbler both decreased in density. In Sector 3 the golden-winged warbler, prairie warbler, rufous-sided towhee, field sparrow, TOTAL, and the number of species present (NOSPP) showed significant increases in density. In Sector 4 significant increases in density were observed in the field sparrow, song sparrow, TOTAL, and NOSPP.

Breeding bird populations--habitat relationships--The relationships between the vegetation and the breeding bird population of the censused areas were analyzed by correlation and multiple regression techniques. Vegetation variables are described in Table 13. Analyses were performed for TOTAL, NOSPP, and those species showing significant increasing or decreasing populations. Appendix B-6 shows results of correlation tests between vegetation variables and year. Those variables with a significant positive correlation increased between 1976 and 1980, while those with a significant negative correlation decreased.

With all sectors combined, correlation tests were performed between vegetation variables and TOTAL, NOSPP, and several individual bird species (Appendix B-7). TOTAL and NOSPP were both significantly and positively correlated with TOTCOV, HERBHT, HERBHC, FORBCOV, and WOODC. Both also showed a nonsignificant negative correlation with GRAMCOV. From the results of these correlation tests, it is evident that the highest density and diversity of breeding birds were found in plots with a high volume of herbaceous vegetation (as indicated by TOTCOV, HERBHT, and HERBHC), the presence of fairly large trees or shrubs, and a high proportion of forbs, as opposed to graminiferous vegetation.

TABLE 14. MEAN BREEDING BIRD POPULATION PER PLOT BY YEAR ON THE OLLIS CREEK MINE

Species	1976	1977	1978	1979	1980
	----------------------	-Mean.	No.-	----------------------	
Yellow-billed cuckoo	0.009	-	-	-	-
Ruby-throated hummingbird	-	-	-	0.009	-
E. phoebe	.018	-	-	-	-
Carolina chickadee	-	-	-	-	0.018
Tufted titmouse	.036*	-	-	-	-
Gray catbird	-	0.014	-	-	.009
Brown thrasher	-	-	-	-	.009
Red-eyed vireo	-	.009	0.018	-	.015
Black-and-white warbler	-	-	-	-	.015
Golden-winged warbler	-	.065	.018	.009	.096
Prairie warbler	.102	.014	.056	.113*	.149*
Ovenbird	.014	-	-	-	-
Common yellowthroat	-	-	-	.018	-
Yellow-breasted chat	.009	-	.009	-	.038
Red-winged blackbird	.182	.124	.405	.323*	.306
Cardinal	-	-	-	-	.009
Indigo bunting	.504	.251*	.280	.458*	.506
Am. goldfinch	.075	-	.009	.019	.028
Rufous-sided towhee	.014	-	.055	.019	.119
Chipping sparrow	-	-	-	.009	-
Field sparrow	.393*	.125	.160	.462*	.653
Song sparrow	.009	.018	.009	.009	.100
TOTAL	1.365*	.620	1.019	1.448	2.070
NOSPP	1.736*	.500*	.962	1.417	2.131

* Significant (ANOVA, $p < 0.05$) within-year, between-sector difference in density.

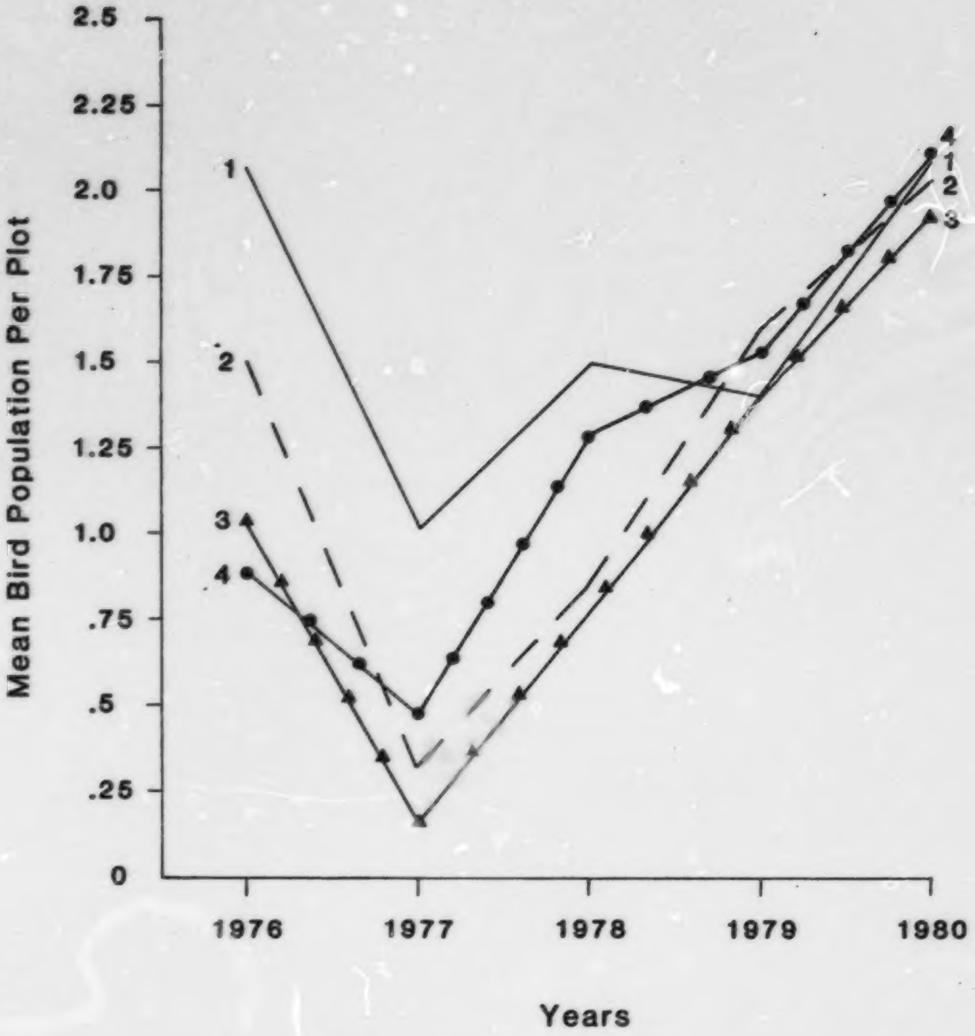

Figure 2. Yearly Changes in Total Breeding Bird Population, Sectors 1-4

Correlation tests were then performed between habitat variables and TOTAL and NOSPP in each sector (Appendix B-8). In Sector 1, there were no significant correlations with TOTAL. WOODC was significantly correlated with NOSPP, while NATCOV showed a strong ($0.10 < p < 0.05$) positive correlation and REVCOV a strong negative correlation with NOSPP. Sectors 2, 3, and 4 showed similar results, i.e., significant positive correlations of TOTAL and NOSPP with TOTCOV, HERBHT, HERBHC, FORBCOV, and woody vegetation variables, and negative correlations with GRAMCOV. To determine which vegetation variables were most important as predictors of TOTAL and NOSPP, multiple regression analyses were performed (Appendix B-9).

Winter bird populations--The winter bird population showed a general increase between 1977 and 1981 (Figure 3, Appendices B-10 through B-13). Sector 1 showed a decrease in the total winter population (WTOTAL) between 1977 and 1978, but the population increased significantly during the 5-year period. The trend of WTOTAL in Sector 3 was similar to that of Sector 1, although the increase was not significant ($0.10 < p < 0.05$). In Sector 2, WTOTAL was highest in 1979 and did not increase significantly between 1977 and 1981. In Sector 4, WTOTAL increased significantly between 1977 and 1981. The mean number of wintering species per plot, WNOSPP, significantly increased between 1977 and 1981 in all sectors. With all sectors combined, both WTOTAL and WNOSPP increased significantly during the course of the study.

With all sectors combined, the hermit thrush, golden-crowned kinglet, cardinal, field sparrow, white-throated sparrow, and song sparrow population differed significantly (ANOVA) between years (Table 15). The Carolina chickadee, winter wren, hermit thrush, golden-crowned kinglet, cardinal, field sparrow, and song sparrow populations all increased significantly between 1977 and 1981 on the whole study area. Several species also showed significantly increasing populations within the individual sectors. These are noted in Appendices B-10 through B-13.

Winter bird populations--habitat relationships--As with the breeding bird population, habitat preferences of the winter birds were analyzed by correlation and multiple regression techniques. The same vegetation variables described in Table 13 were used, and correlations were made between late summer vegetation and the bird population of the following winter. Analyses were performed for WTOTAL, WNOSPP, and those species showing significant population changes during the study period.

With all sectors combined, WTOTAL and WNOSPP showed similar results, in that both were positively correlated with TOTCOV, NATCOV, HERBHT, HERBHC, HERBDIV, and FORBCOV and negatively correlated with GRAMCOV (Appendix B-14). These results were similar to the correlations with TOTAL and NOSPP except that the winter bird population showed less preference for WOODC and a distinct preference for NATCOV over REVCOV and for FORBCOV over GRAMCOV. Results of correlation between vegetative variables and WTOTAL and WNOSPP, broken down by sector, are shown in Appendix B-15. Multiple regression analyses were performed to determine which vegetation variables gave the best predictions of WTOTAL and WNOSPP (Appendix B-16).

Small mammal populations--Trapping success varied greatly between years and sectors (Table 16, Figure 4). In Sectors 2, 3, and 4, trapping success

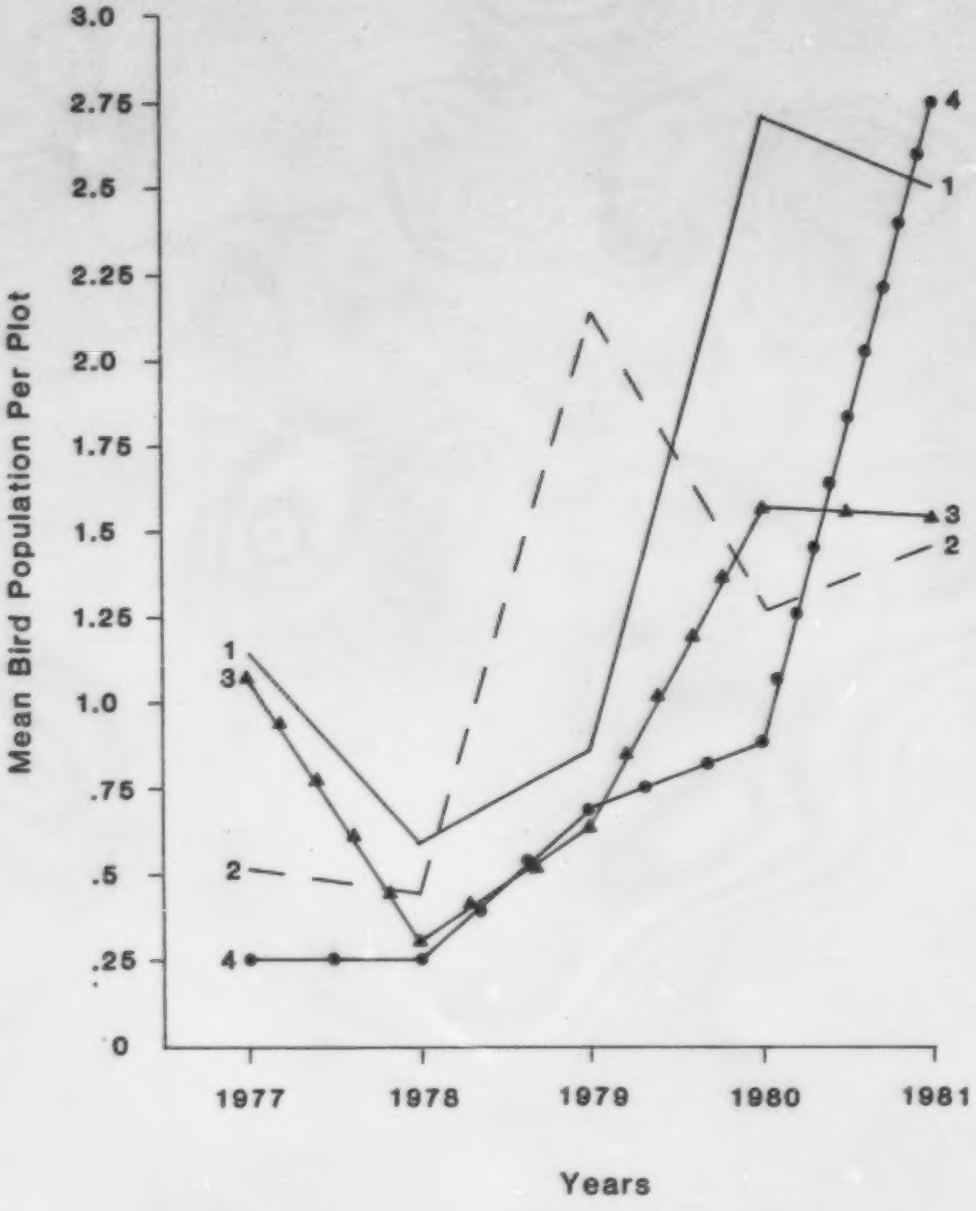

Figure 3. Yearly Changes in Total Wintering Bird Population, Sectors 1-4

TABLE 15. MEAN WINTER BIRD POPULATION PER PLOT BY YEAR

Species	1977	1978	1979	1980	1981	5-year mean
Mallard	-	-	-	0.009	-	0.002
Red-tailed hawk	0.005	-	-	-	-	.001
Mourning dove	-	-	0.005	-	-	.001
Pileated woodpecker	-	-	-	-	0.005	.001
Red-bellied woodpecker	-	-	-	-	.005	.001
Downy woodpecker	-	-	-	.005	.033	.008
Blue jay	.009	0.005	.009	-	.005	.006
Common crow	.024	-	-	-	-	.005
Carolina chickadee	-	-	.042	.060	.208	.062
Tufted titmouse	-	-	.014	.019	.009	.008
White-breasted nuthatch	-	-	-	-	.005	.001
Red-breasted nuthatch	-	-	-	-	.014	.003
Winter wren	-	-	.005	.005	.061	.014
Carolina wren	-	-	-	.014	.009	.005
Brown thrasher	-	-	-	.005	-	.001
Am. robin	-	-	.005	-	.005	.002
Hermit thrush	-	-	-	.014	.042*	.011†
E. bluebird	-	-	-	.019	-	.004
Golden-crowned kinglet	-	-	.005	.024	.288*	.063†
Myrtle warbler	-	-	-	.009	-	.002
Red-winged blackbird	-	-	.005	-	-	.001
Cardinal	.071*	.047	.009	.061*	.156*	.069†
Am. goldfinch	-	-	.024	.009	-	.007
Rufous-sided towhee	-	-	-	.005	.014	.004
Slate-colored junco	.571	.236	.630*	.566	.660	.348
Field sparrow	-	.019	.160*	.231*	.071	.096†
Tree sparrow	-	.071	.033	-	-	.021
White-throated sparrow	.038	-	.033	.151	.042*	.053†
Fox sparrow	-	-	-	-	.005	.001
Song sparrow	.014	.033	.104*	.231*	.307*	.138†
Unidentified sparrow	.047	-	-	-	.005	.010
WTOTAL	.779	.411	1.083	1.437	1.949	1.132
WNOSPP	.716	.696	1.008	2.121	2.995	1.884

* Significant (ANOVA, $p < 0.05$) within-year, between-sector difference in density.

† Significant between-year difference in density.

TABLE 16. SMALL MAMMAL TRAPPING SUCCESS, TOTAL CAPTURES PER 100 TRAP NIGHTS

Sector		1976	1977	1978	1979	1980	5-year mean
		----------	----------	----------	No.	----------	----------
1	Summer	2.5	3.69	5.79	1.98	2.37	3.27
	Fall	1.98	4.21	5.40	1.45	1.45	2.90
	Combined	2.24	3.95	5.60	1.72	1.91	3.08
2	Summer	5.53	3.16	1.85	.26	1.19	2.40
	Fall	1.98	0	.26	.53	.66	.69
	Combined	3.76	1.58	1.06	.38	.93	1.54
3	Summer	6.71	2.37	5.26	2.64	2.37	3.87
	Fall	14.61	3.16	6.32	2.37	2.37	5.77
	Combined	10.7	2.77	5.79	2.51	2.37	4.83
4	Summer	2.90	.26	2.24	.40	.60	1.28
	Fall	-*	.66	.66	.40	.13	.46
	Combined	2.90	.46	1.45	.40	.37	1.12

* Not trapped.

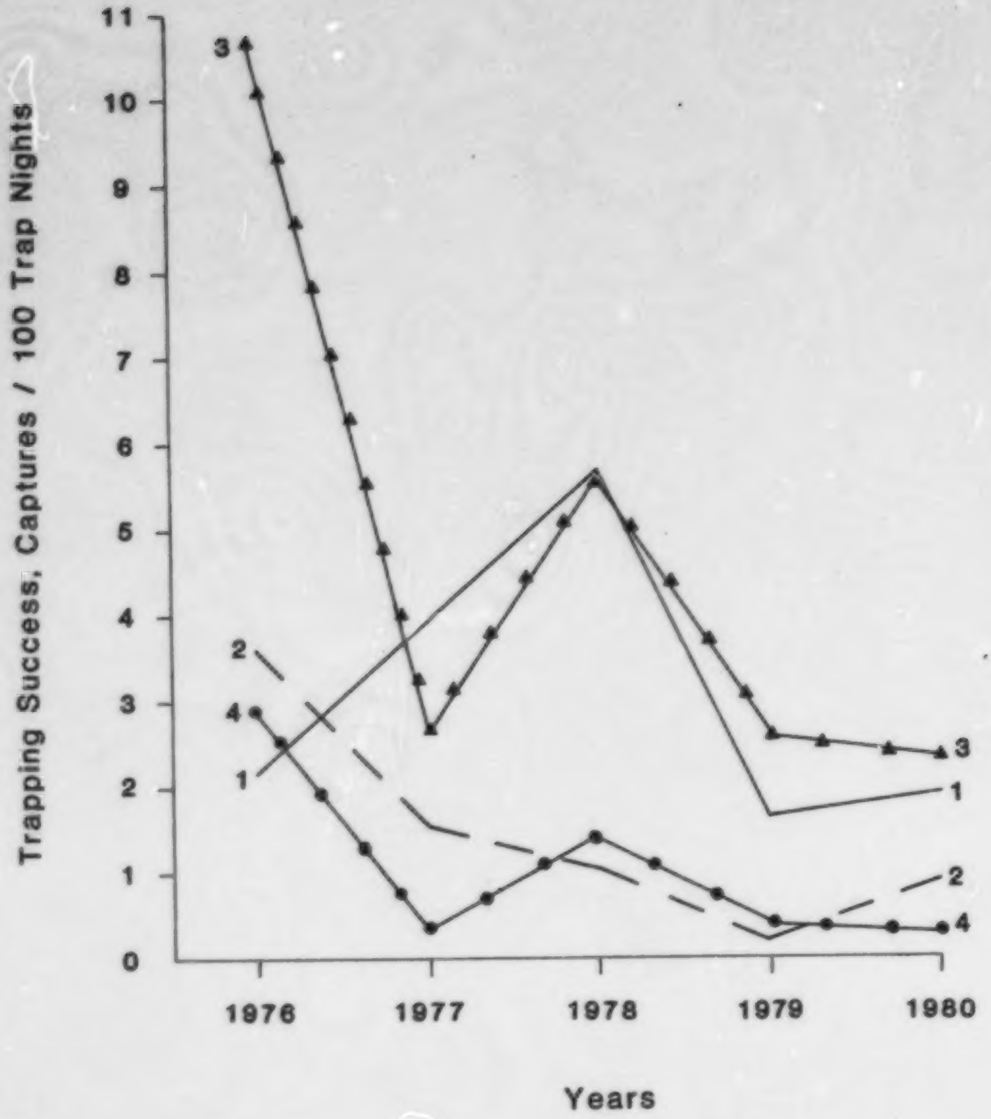

Figure 4. Yearly Changes in Small Mammal Population, Sectors 1-4

was highest during 1976, and lower in following years. All sectors showed significant decreases during the 5-year period, and the decrease was most pronounced in Sector 2. Sector 1, which had the most mature vegetation at the beginning of the study, showed the smallest population decrease.

In all sectors, the small mammal population, expressed as total captures per 100 trap nights, was negatively correlated with NATCOV, HERBHT, HERBHC, and FORBCOV. In Sectors 1 and 3, trapping success during the 5-year period was positively correlated with REVCOV, and in Sectors 2 and 3, trapping success was positively correlated with GRAMCOV. The correlation with REVCOV and GRAMCOV was possibly due to increased food available from heavy seeded annual grasses, such as rye, which were sown during 1975-1976 on Sector 3, and during 1976-1977 on Sector 4. The abundant food source, available for only one season, probably accounted for the high trapping success in Sector 3 in 1976 and the decrease in trapping success in 1977. Sector 2 was sown in 1974-1975, and any resultant increase in the small mammal population probably occurred before trapping began.

Species diversity (H´) also varied greatly between sectors and years and did not show significant trends (Appendix B-17). Sector 1 had the highest combined spring and fall species diversity during each year, but because of the great variability in other sectors, it was difficult to analyze trends in species diversity. The largest number of species, 10, was found in Sector 1, followed by Sector 3 with 9 species, Sector 2 with 7 species, and Sector 4 with 3 species. The high number of species and high species diversity in Sector 1 were probably due to the area's great diversity of microhabitats, which included moist pondside thickets of grasses and herbs, autumn-olive shrubs, briars, and stands of pine and black locust. The dominant mammal species was the white-footed mouse, which accounted for 86.2 percent of all captures. The percentage of captures made up by white-footed mice was lowest in Sector 2, with a 5-year average of 62 percent, and highest in Sectors 3 and 4, at 92 and 91 percent, respectively. The percentage of captures made up by this species increased during the 5-year study period in Sectors 1 and 3 and decreased in Sectors 2 and 4.

Other mammal species caught were the meadow vole, in all sectors; the house mouse, in Sectors, 1, 3, and 4; the hispid cotton rat and harvest mouse in Sectors 1, 2, and 3; the smoky shrew in Sectors 1 and 2; the short-tailed shrew in Sectors 1 and 3; the southeastern shrew in Sectors 2 and 3; the southern bog lemming, eastern cottontail, and eastern chipmunk in Sector 1; the long-nosed shrew in Sector 2; and the eastern wood rat in Sector 3.

Discussion

Previous studies relating breeding bird populations to vegetation variables have shown bird species diversity increases during succession (Johnston and Odum 1956, Shugart and James 1973) and also with vegetative complexity, both in a vertical profile (MacArthur and MacArthur 1961) and a horizontal profile (Roth 1976). Bird community predictions based on vertical profile measurements have been most successful within series of similar forest habitats (Willson 1974). In early successional habitats, such as the Ollis Creek mine, measures such as percentage of vegetative cover and the spatial heterogeneity of shrubs have predicted bird species diversity (Willson 1974, Roth 1976).

In this study, vegetation sampling was designed to document revegetation of the mine and was adapted for use in analyzing bird population changes. Vegetation variables were based on percentage of herbaceous cover and number of woody stems on a plot. The increases in the breeding bird density (TOTAL) and diversity (NOSPP) were positively correlated with increases in total vegetative cover (TOTCOV), forb cover, height and volume of herbaceous cover (HERBHT and HERBHC), and the number of trees and shrubs. The bird population was also negatively correlated with revegetative cover (REVCOV) and graminiferous cover (GRAMCOV). Sector 1 had the highest breeding bird population during the first years of the study and showed less increase during the course of the study than did the other sectors. This was because Sector 1 had sufficient cover at the beginning of the study and did not change as much as did the other sectors.

The multiple regression equations explained only 10 to 39 percent of the variation in TOTAL and NOSPP in Sectors 1 to 3 and 79 percent of TOTAL and 41 percent of NOSPP in Sector 4. Correlations with habitat variables also failed to account for the decrease in the breeding bird population that occurred between 1976 and 1977. Among the possible explanations for the low correlations are observer differences, regional bird population fluctuations, and response of birds to habitat parameters not measured in the vegetative sampling. Censuses were done by different individuals in the early years of the study and their results may have varied because of misidentification of birds, differences in hearing ability and recording techniques, and different attention to plot boundaries.

The unusually severe winters of 1977 and 1978 caused population declines in several breeding species which also winter in the region. Of the affected species, the eastern phoebe was the only one regularly occurring on the study area, and its population declined after 1976. Most of the other species breeding on the study area were migratory, and their populations were probably not directly affected by severe winter weather. An analysis of the results of several U.S. Fish and Wildlife Service Breeding Bird Survey (BBS) routes in the area showed that, except for the red-winged blackbird, there was no regional decrease between 1976 and 1977 in the most abundant birds on the Ollis Creek area. The red-winged blackbird showed a slight decrease on BBS routes, and also on the Ollis Creek area.

The winter bird population also showed year-to-year variations and a general increase over the course of the study. The winter bird density (WTOTAL) and diversity (WNOSPP) were positively correlated with total cover, natural cover, HERBHT, HERBHC, HERBDIV, and FORBCOV and negatively correlated with revegetation cover and graminiferous cover. The response to increases in herbaceous cover volume and naturally occurring forb cover was expected since these cover conditions presumably provided a good food supply and shelter for the wintering birds. The negative correlation with REVCO and GRAMCOV was probably due to the lower food production of the grasses, such as fescue, broomsedge, and weeping lovegrass, as opposed to the high food production of forbs, such as lespedeza sericea and goldenrod. REVCOV and GRAMCOV also decreased during the course of the study.

Some of the year-to-year variation in the winter bird population was due to weather conditions, both in the study area and in other areas of eastern North America. Some of the birds wintering in the Ollis Creek area, such as cardinals and chickadees, are permanent residents and move only short distances during the winter. Others, such as sparrows and juncoes, migrate long distances. During unusually severe winter weather, some of the permanent residents may die because of food stress. The migratory species, however, may adjust their migratory patterns and winter further south than normal and then move northward as weather conditions improve.

Weather information from the National Oceanic and Atmospheric Administration (1977-1980) for weather stations in the region showed that the winter of 1977 was the most severe of the 5 years censused but that heavy snow cover was also present in 1978 and for a shorter period in 1979. Because of the inaccessibility of the area during 1977, winter censuses were not conducted until late February and early March after weather conditions had ameliorated. Most censuses in following years were conducted in January. The releatively high bird density in 1977 may have been due to northward movement of many migratory species that were earlier displaced further south. Some species that showed regional declines following the severe weather of 1977, including the winter and Carolina wrens, hermit thrush, and golden-crowned kinglet, increased in 1980 and 1981 as populations increased throughout eastern North America and as the vegetation on the mine became better suited to their habitat preferences.

Many of the breeding and wintering species had distinct habitat preferences and some of these were not shown by the vegetation sampling. For example, red-winged blackbirds nested in cattails and willows found around ponds on the mine. They were recorded on plots containing ponds and in surrounding plots, where the birds foraged. The vegetation variables used here did not distinguish cattails from other graminiferous species. As the ponds fill in and the cattails give way to sedges and other grasses, the red-winged blackbird population will probably decline, and this may have already begun during 1979 and 1980 in Sectors 1, 2, and 4. Other distinct habitat preferences were the golden-crowned kinglet's preference for pines, the hermit thrush's preference for fruit-bearing shrubs and vines, especially sumac and greenbrier, and the eastern phoebe's preference for areas near highwall cliffs which provided suitable nesting habitat.

Previous studies of small mammal populations on strip-mined lands have found the white-footed mouse and deer mouse to be the dominant species (Verts 1959, DeCapita and Bookhout 1975, Sly 1976). These studies found the deer mouse more abundant on early successional areas and the white-footed mouse more abundant in older areas with woody vegetation. In this study no deer mice were captured, possibly because the mines, surrounded by heavily wooded, mountainous terrain, were too far removed from old fields to be invaded by deer mice. The white-footed mouse population decreased during the course of the study, while the proportion of the small mammal population composed by white-footed mice increased in Sectors 1 and 3, which had the most woody cover, and decreased in Sectors 2 and 4. DeCapita and Bookhout (1975) found that white-footed mouse populations increased from 1966 to 1967 and 1973 to 1974 and attributed some of this increase to vegetative change. The white-footed mouse was the only species captured by Sly (1976) on Indiana mine lands with dense woody cover. On other areas, with less woody cover and more herbaceous cover, Sly (1976) reported a greater diversity of small mammals. On the Ollis Creek mine the greatest diversity of small mammals was in Sector 1, which had the most advanced woody cover, in addition to the greatest diversity of microhabitats.

The correlations of the small mammal population with the vegetation parameters showed some trends, but there were obviously several other factors that influenced the population. These included small mammal population cycles, predation, and weather conditions. Populations cycles have been described for meadow voles (Golley 1962) and cotton rats (Odum 1955), but the sample of these species from the Ollis Creek mine was too small to analyze cyclic fluctuations. *Peromyscus* populations can vary erratically between years and over a limited geographic area (Jameson 1955), and the white-footed mouse is capable of rapid population increases in response to abundant food supplies. Predator populations, especially red and gray foxes, may have increased in response to the high small mammal population present in 1976 and then depressed the small mammal populations in following years. No systematic efforts were made to census predator population on the Ollis Creek mine. Weather conditions probably also affected trapping success, because winter weather probably affected over winter survival, and temperature and rainfall during the trapping periods influenced trapping success.

Summary

Breeding birds and wintering birds were censused on permanent plots in the four sectors of the Ollis Creek mine from the summer of 1976 through the winter of 1981. All four sectors showed increases in the breeding and wintering bird populations during the course of the study, although the various sectors did not increase uniformly from year to year. The increases in the bird population were correlated with increases in the total vegetation cover, percentage of natural cover, percentage of forb cover, herbaceous cover height and volume, and the number of trees and shrubs. The bird population was also negatively correlated with the percentage of revegetation cover and graminiferous cover. The winter bird population had a preference for naturally occurring herbaceous vegetation, as opposed to reclamation materials. The winter bird population was also influenced by weather conditions.

Small mammals were sampled by snap-trapping permanent traplines in each sector. Small mammal populations were highest during the first years of the study, when there was an abundance of heavy-seeded grasses on the area. Sector 1, which had the most vegetation at the beginning of the study and the highest diversity of microhabitats, had a more stable and more diverse small mammal population than did the other sectors.

SECTION 3

AQUATIC SYSTEMS

Monitoring of Ollis Creek and its tributaries was initiated in June 1970 and continued through October 1972 (during mining and conventional reclamation) to assess the impact of mining on stream fauna and water quality (TVA 1972 a,b). Monitoring was resumed in August 1975 and continued through July 1980 to evaluate effects of intensive remedial reclamation performed from 1975 to 1978 (Table 1) on water quality and aquatic biota in Ollis Creek and its tributaries. The analysis included a comparison of data with those collected from an undisturbed watershed.

DESCRIPTION OF STUDY AREAS

Ollis Creek watershed encompasses an area of 28 km^2 (11 mi^2). The stream is approximately 15 km (9.4 mi) long and has a gradient of 20 m/km (105 ft/mi). Substrate materials are predominantly boulders and bedrock.

No Business Creek, located in a nearby undisturbed watershed, was utilized as a reference stream to compare water quality, fish, and macroinvertebrates with those in Ollis Creek. The watershed area is 7 km^2 (2.7 mi^2), with a stream length of 3.5 km (2.2 mi). Substrate is composed of a mixture of boulders, rubble, gravel, and sand.

Although there are some differences in flow and watershed size, physical and chemical characteristics were similar, and comparable stations were selected from each stream. Ollis (Tennessee River drainage) and No Business (Cumberland River drainage) Creeks have slightly different species assemblages; however, the two watersheds are sufficiently similar to allow evaluations of biotic potential.

METHODS AND MATERIALS

Water Quality

Water quality samples were taken monthly August 1975 through December 1976 and quarterly January 1977 through July 1980 at each of the stations shown in Figure 1. Dissolved oxygen and pH were measured onsite with portable meters. Alkalinity and acidity were determined within a few hours by titration. A portion of the sample was preserved for laboratory analyses.

An important factor in determining fluctuations within different measured water quality parameters was precipitation (see page 3) and the resultant changes in discharge. Flow was not measured during the study; however, precipitation immediately prior to sampling was examined for potential influence on water quality parameters.

Aquatic Macroinvertebrates

Aquatic macroinvertebrates were sampled monthly August 1975 through December 1976 and quarterly January 1977 through July 1980. Four Surber samples were collected at each station on Ollis Creek, its tributaries, and No Business Creek. Samples were preserved in 10-percent formalin and returned to the laboratory. Qualitative samples were also collected in the vicinity of each station to compile a species list. Macroinvertebrates were picked from samples, identified to the lowest possible taxon, and weighed (blot dry weight) to the nearest 0.1 mg. Samples from the 1970-1972 period were collected with a sweep net and are qualitative only.

In May 1977 a survey was made of aquatic biota in Reservoir 1. Beginning at the dam (on the downstream end of the reservoir) an Eckman dredge sample was taken every 6.2 m (20 ft) along a transect across the reservoir. Depth of each sample was recorded. A transect was repeated approximately every 9.2 m (30 ft). Vertebrates and macroinvertebrates picked from the samples were identified to the lowest taxon, enumerated, and weighed.

Fish

All stations on Ollis Creek, its tributaries, and No Business Creek were sampled monthly August 1975 through December 1976 and quarterly January 1977 through July 1980 with a battery-powered, pulsed dc backpack electrofishing unit. A 30-m (100-ft) section of stream with both a pool and riffle was fished at each station. Electrofishing began at the lower pool end of each stream section and proceeded upstream toward the riffle. Fish stunned by the current were collected, identified to species, measured, weighed, and returned to the water alive. Fish of uncertain identity were preserved in 10-percent formalin and returned to the laboratory for identification.

Two surveys, April and September 1977, were performed utilizing gill and hoop nets to determine species present in Reservoir 1 and to obtain fish for analysis of metal concentration. Fish collected to be analyzed for heavy metals were frozen with dry ice and transported to the laboratory. Tissue to be analyzed was ground to as homogenous a sample as possible. Weights of tissue varied from 0.25 to 0.5 g. Perchloric acid and nitric acid were added to the sample and heated. Nitric acid was added until all material was digested. Metal concentration was determined by aspiration into an atomic absorption spectrophotometer.

Because of the large quantity of data collected, water quality and biological trends were examined in depth from only four stations in order to provide watershed characterization. Thompson Creek (Station 8) and the unnamed tributary (Station 7) designated in this report "Unnamed Tributary" are in juxtaposition to the land sector initially receiving the remedial reclamation. Laurel Branch received treatments beginning a year later than those for Thompson Creek or Unnamed Tributary. Ollis Creek Station 1 was located downstream in order to determine any improvements related to secondary changes or total watershed recovery.

RESULTS AND DISCUSSION

Water Quality--Streams

Degradation of water quality, during both surface mining and conventional reclamation in the Ollis Creek watershed, was due to acid mine drainage (Zarger et al. 1979). Water quality parameters collected from an unmined reference stream, No Business Creek (Appendix C-1), further substantiates effects of acid mine drainage in the Ollis Creek watershed. Tributary and mainstream water quality stations in Ollis Creek were considered independently when evaluating changes that might affect overall water quality in Ollis Creek proper.

Thompson Creek--Water quality data revealed Thompson Creek to be impacted by acid mine drainage as early as 1971 (Appendix C-2). Remedial land treatment in the Ollis Creek watershed began in Sector 2 (Figure 1) in late 1974 and early 1975. During remedial treatment (1975-1976), levels of several indicators of acid mine drainage, such as pH, sulfate, iron, and manganese, began to improve. The pH levels increased slightly during remedial treatment (fall quarter 1975 through fall quarter 1978) and by July 1978 the last pH less than 4.0 was recorded (Figure 5). Postreclamation periods (winter quarter 1979 through summer quarter 1980) contained a slight pH increase. The pH of Thompson Creek in all 1980 samples was 4.5, suggesting stabilization at that level. There appeared to be some seasonal trends, with lowest pH levels recorded in low-flow periods and highest pH levels recorded in fall and winter high-flow periods.

Sulfate ion concentration is one of the most reliable indicators of acid mine drainage severity (Herricks 1973). Sulfates are usually present in low concentrations (<20 mg/l) in soft water streams of unmined watersheds (e.g., No Business Creek, Appendix C-1) but high in acid mine drainage. Sulfate levels for Thompson Creek (Appendix C-2 and Figure 6) increased from a minimum of 35 mg/l during early mining and conventional reclamation (1971-1972) concomitant with decreases in pH. Peak levels of 180 mg/l and 230 mg/l were recorded in spring and summer quarters 1972, respectively. Average sulfate levels recorded in 1980 were 36 percent lower than the average for the "during reclamation treatment" phase. However, the minimum sulfate level recorded in 1980 (48 mg/l) was still above unmined levels (Appendix C-2).

Iron values for the Thompson Creek watershed (Appendix C-2 and Figure 7) were generally within an acceptable range with only one sample (January 1980) exceeding 1.0 mg/l. This value is thought to be an anomaly and possibly represents a transcription error (i.e., 0.17 to 1.70 mg/l). Associated with this elevated iron value, there was no concomitant change in pH, sulphate, manganese, or turbidity; and no rain event was recorded on that or the preceding day. Therefore, this outlier was omitted from further calculations. Most iron concentrations recorded at this station were within accepted water quality limits for freshwater aquatic life (1.0 mg/l) and domestic use (0.3 mg/l) based on EPA criteria (1976).

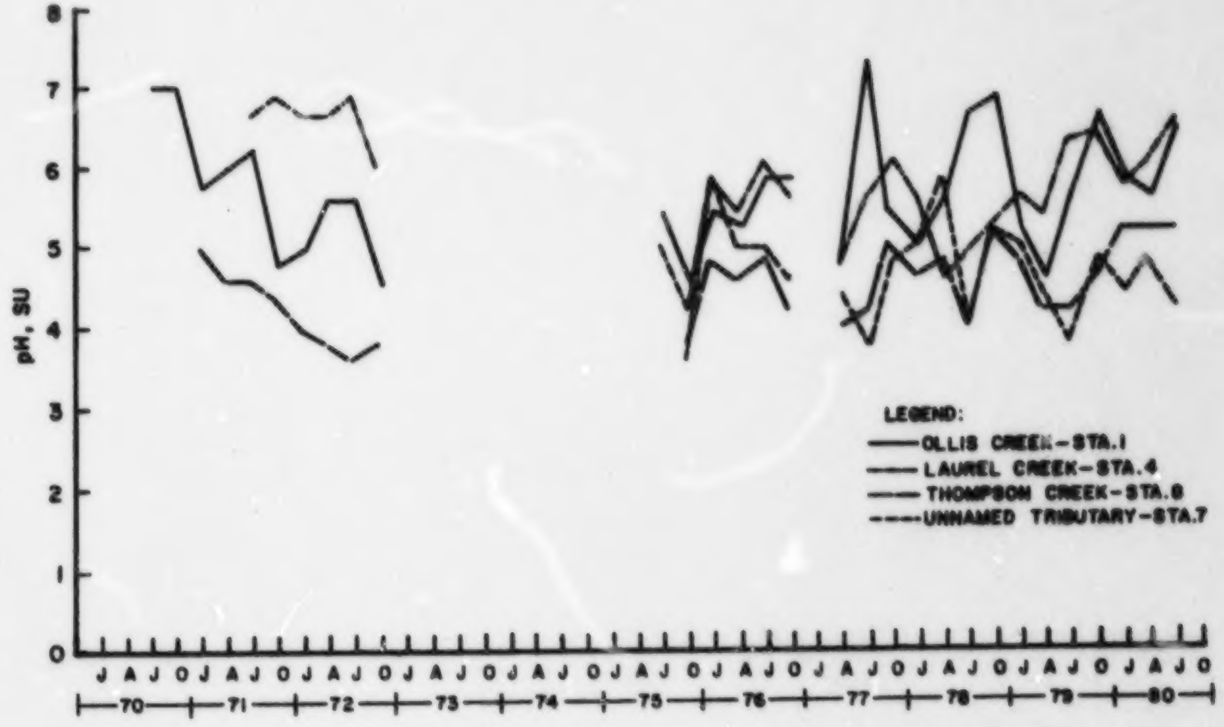

Figure 5. Comparison of pH Levels at Selected Stations in the Ollis Creek Watershed

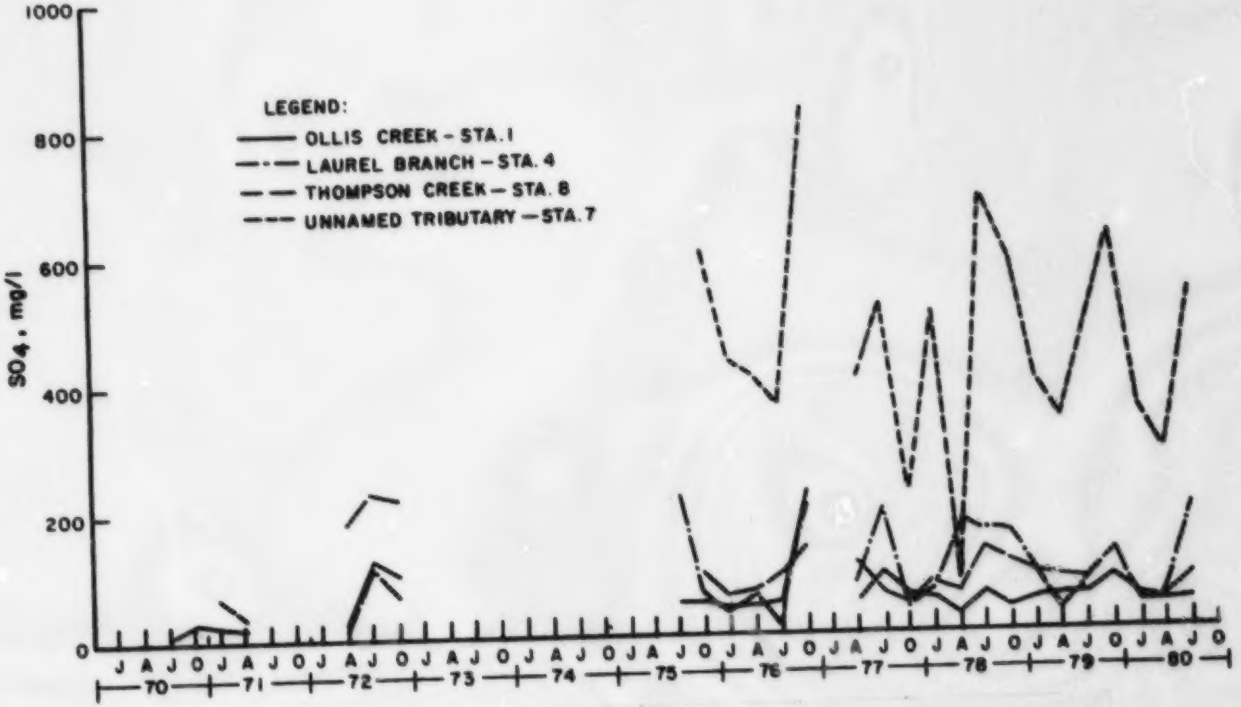

Figure 6. Comparison of Sulfate (SO_4) Concentrations at Selected Stations in the Ollis Creek Watershed

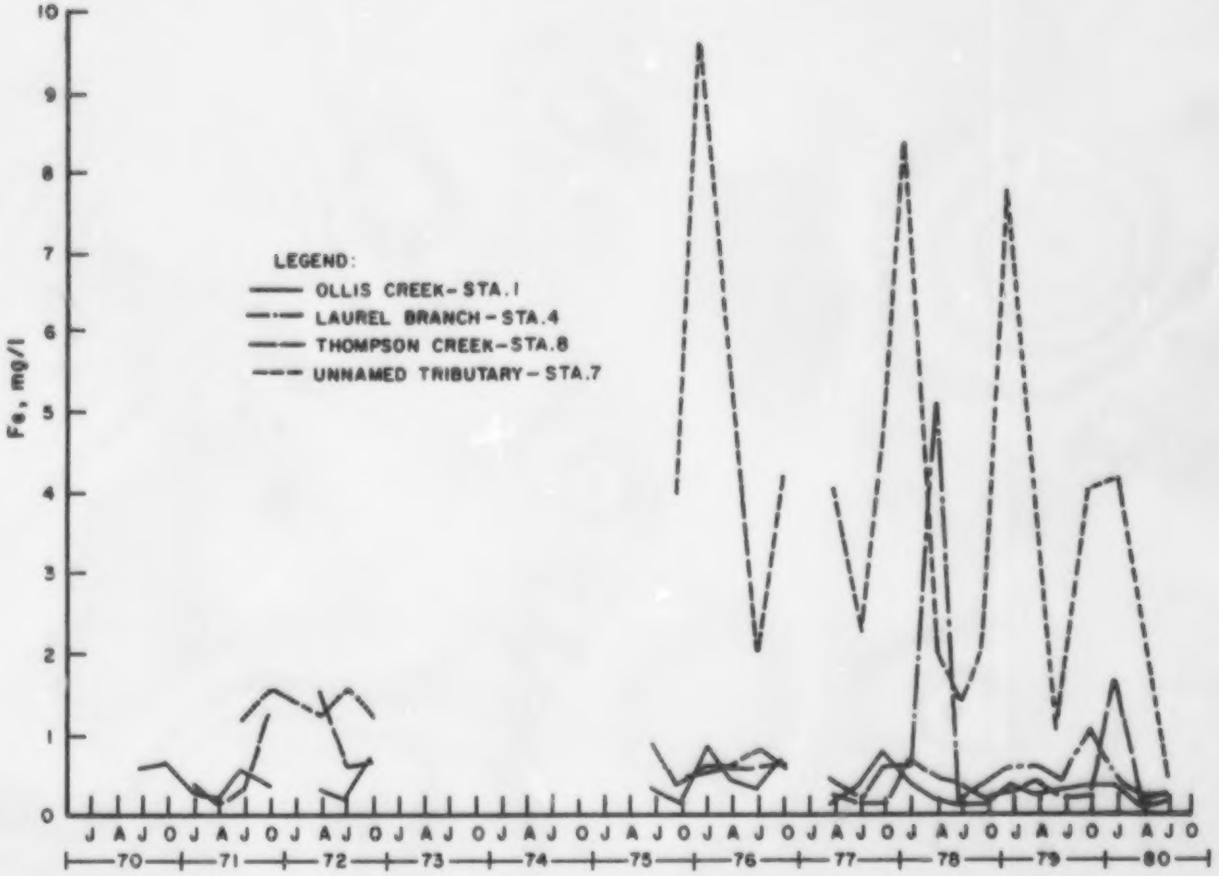

Figure 7. Comparison of Iron (Fe) Concentrations at Selected Stations in the Ollis Creek Watershed

Manganese levels in Thompson Creek declined dramatically after the period of mining and conventional reclamation in 1971 and 1972 (Appendix C-2 and Figure 8). The mean concentration for manganese during mining was 14.9 mg/l. During remedial treatment manganese occurred at a mean concentration of 1.88 mg/l. Fertilizing and liming during remedial treatments in fall of 1974 and spring of 1975 are probably responsible for the initial decline in manganese concentrations recorded at this station. Manganese concentrations in winter and spring quarters of 1980 were 0.73 mg/l and 0.93 mg/l, respectively.

Unnamed Tributary--The Unnamed Tributary Station 7, in Sector 3, became a permanent water quality sampling station in late 1975. Remedial land reclamation began in late 1975 in this sector and concluded with tree planting in 1977. In Unnamed Tributary (Appendix C-3 and Figure 5) a pH value of 3.5 was recorded in fall 1975 immediately before remedial treatment was initiated in this sector. A pH of 5.8 recorded during winter quarter 1976 was almost certainly the direct result of fertilizing and liming activities. This appears to be an unstable system, with wide fluctuations in pH levels during and after remedial treatment (1976 through July 1980). Lowest pH levels were generally found in summer, with highest pH levels in fall or early spring. Average hydrogen ion concentrations at this station during remedial treatment resulted in a pH of 4.8, while it was 4.7 after remedial treatment. A pH of 3.8 was recorded as of July 1979.

Sulfate values for Unnamed Tributary (Appendix C-3 and Figure 6) were the highest in Ollis Creek watershed. Proximity of Unnamed Tributary to spoil piles as well as the presence of a filled silt basin across this stream probably resulted in these high sulfate levels. During remedial treatments, sulfates oscillated between 820 mg/l (October 1976) and 220 mg/l (October 1977). After remedial treatment the lowest sulfate value (75 mg/l) found was in spring 1978. The annual average for sulfates decreased from 561 mg/l in 1978 to 383 mg/l in 1980, with an overall average of 463 mg/l after remedial treatment.

The Unnamed Tributary, unlike Thompson Creek, had high iron values. Iron levels (Appendix C-3 and Figure 7) present at this station were too high to be acceptable for either freshwater aquatic organisms or domestic water use. Mean iron level during the period of remedial treatment (1976-1977) was 4.5 mg/l, with a mean of 3.4 mg/l after remedial treatment (1978 through July 1980). These elevated values were highly seasonal in nature, with the maximum concentrations present in January during high-flow conditions. Lowest iron levels were found in July during low-flow periods. Maximum and minimum values decreased throughout the study. When 1980 data are included, there is a dramatic decrease in iron values.

Manganese levels (Appendix C-3 and Figure 8) in Unnamed Tributary decreased from 1976 until 1977 (during remedial treatment). Fertilization and liming activities in Sector 3 probably accounted for the initial reduction in manganese levels. However, manganese increased (25.0 mg/l in winter 1978 and 23.0 mg/l during summer 1978) when remedial treatment activities ceased. In 1978 mean manganese concentration was 18.1 mg/l. This mean decreased to 13.5 and 12.6 mg/l in 1979 and 1980, respectively. The average concentration of manganese during the period of remedial treatment (1976-1977) was 8.1 mg/l, while the post reclamation mean increased to 14.7 mg/l, largely the result of increases in 1978. Apparently fertilizing and liming resulted in only short-term reduction in manganese levels at this highly impacted

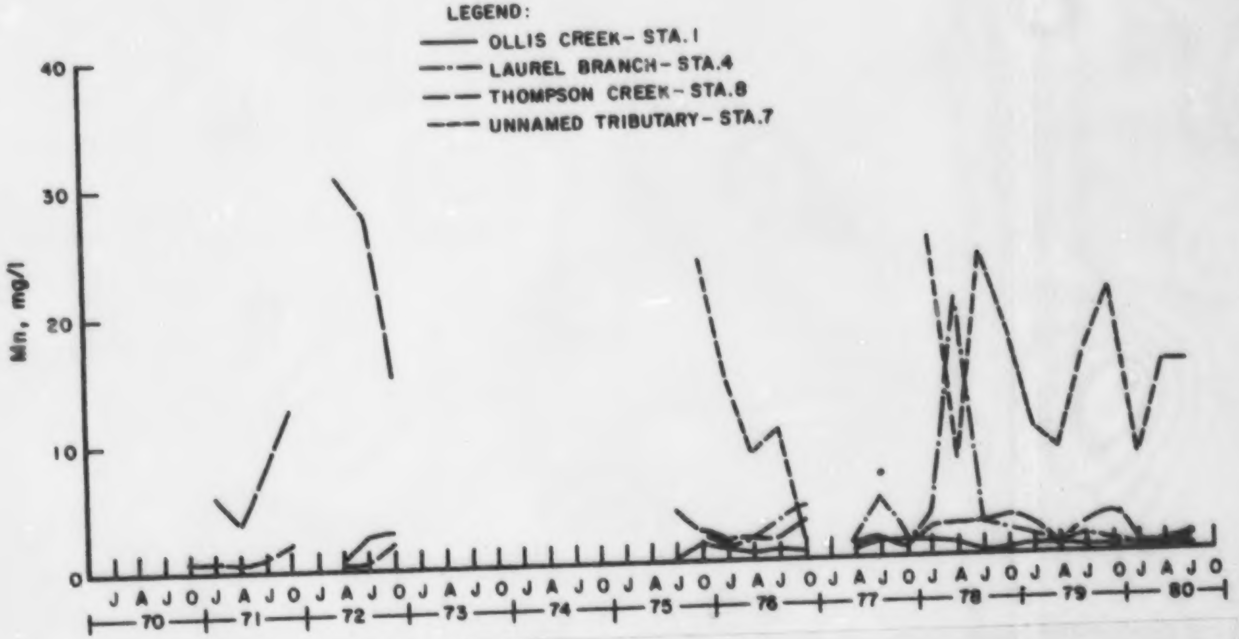

Figure 8. Comparison of Manganese (Mn) Concentrations at Selected Stations in the Ollis Creek Watershed

station. Several years were required after completion of remedial treatments before a downward trend in concentrations was evident.

Laurel Branch--Laurel Branch, Station 4, had only a small part of its lower watershed affected by mining in 1970-1972 (Appendix C-4). Documented perturbations of water quality parameters were due more to runoff from road construction (e.g., coal haul roads) than activities associated with surface mining. Laurel Branch is in Sector 4, where limited remedial treatment was conducted from 1976 until 1978. High turbidity was a problem in Laurel Branch in 1975 associated with erosion from roads constructed with no runoff control and no revegetation. Turbidity during limited remedial treatment (1976-1978) and the post reclamation period (1979-1980) was not unacceptably high (averaging 7.4 Jackson turbidity units (JTU)).

In Laurel Branch pH values (Appendix C-4 and Figure 5) were highest during mining and conventional reclamation (1971-1972), averaging 6.6. In 1975 (after conventional reclamation), pH values of 5.1 and 4.2 were recorded in summer and fall quarters. Slight improvement of this parameter from a mean of 5.5 for the period 1976-1978 (during limited remedial treatment) to a mean of 5.9 during 1979 and 1980 (post reclamation) was found. Also, maximum pH levels recorded in 1979 and 1980 were higher than in 1976, 1977, and 1978.

Following mining activities in 1971-1972 high levels of sulfate have been present in the watershed (Appendix C-4 and Figure 6). Sulfate concentrations have oscillated seasonally since mining. The maximum sulfate concentration found in Laurel Branch was 220 mg/l (summer quarter 1975), with mean values of 107 mg/l from 1976 to 1978 and 84 mg/l from 1979 to July 1980.

Iron concentrations were slightly elevated (mean 1.3 mg/l) during mining and conventional reclamation (1971-1972) (Appendix C-4 and Figure 7). Iron has been at an acceptable level from 1975 to July 1980 except for a peak reading of 5.0 mg/l recorded spring quarter 1978.

Manganese concentrations for Laurel Branch (Appendix C-4, and Figure 8) increased during mining and conventional reclamation (1971-1972), fluctuated during limited reclamation work (1976-1978), and declined from 1979 through July 1980 (post reclamation). Treatment of Sector 4 by liming and fertilizing probably contributed to the reduction of manganese concentrations. The peak value for manganese (20 mg/l) recorded in spring quarter 1978 occurred simultaneously with elevated iron, sulfate, turbidity, and total acidity as well as decreased pH. Although no rainfall was recorded at the meteorological station at the water treatment plant, this abrupt water quality change may have been the result of a localized thunderstorm. Also, this area was utilized heavily by 4-wheel drive vehicles, and any vehicle crossing the stream earlier would have disturbed sediments and altered water quality.

Ollis Creek--At Ollis Creek Station 1, the station furthest from mining, there were degraded pH levels (Appendix C-5 and Figure 5) during the period of mining and conventional reclamation (1971-1972). Although premining pH measurements were 7.1 and 6.9, the mean pH from 1970 through 1972 was 5.7. During remedial treatments, there was a slight improvement in pH from 1976 through 1978, with a mean pH of 5.8 and quarterly ranges from 4.8 to 7.2. The pH levels at this site from 1979 to July 1980 continued to improve and ranged from 5.5 to 6.4.

At Ollis Creek Station 1, sulfate levels increased (Appendix C-5 and Figure 6) soon after strip mining began in the watershed (1971-1972). Sulfate levels did not return to the low levels recorded prior to mining. The mean level for sulfates was 55 mg/l during the period of mining and conventional reclamation. During the years of remedial treatment (1976-1978) average sulfate concentration was 60 mg/l. After treatments were completed sulfate levels decreased to a post reclamation average (1979 and 1980) of 52 mg/l. By 1980 the average had decreased to 45 mg/l. Although sulfate levels at Station 1 are less than those recorded for the Unnamed Tributary, Thompson Creek, and Laurel Branch, sulfate remained nearly double the 20 mg/l expected for an unmined softwater stream.

Iron levels at the lower Ollis Creek station improved after the period of mining. Iron (Appendix C-5 and Figure 7) has been less than 1.0 mg/l throughout the Ollis Creek study; however, it was not until 1979 and 1980 (post reclamation) that the mean value for iron decreased to the water quality criterion established for domestic use (0.3 mg/l). Iron peaked at 0.86 mg/l during winter quarter 1976, the initiation of remedial treatment. Lowest iron levels reported were 0.09 mg/l and 0.13 mg/l during spring and summer quarters 1980, respectively (post reclamation).

Manganese levels at Ollis Creek Station 1 increased from 1970 to 1972 (Appendix C-5 and Figure 8) as a result of strip mining activities in the upper portion of the watershed. During remedial treatment (1976-1978) and post reclamation periods (1979 through July 1980), manganese levels, for the most part, continued to decline; however, these improved manganese concentrations still exceeded levels recommended by EPA (1976).

Water quality was never degraded at Ollis Creek Station 1 to the extent documented at Ollis Creek tributaries, which are closer to actual strip mining activity (e.g., Thompson Creek and Unnamed Tributary). Also, water quality at the lower Ollis Creek Station 1 (Ollis Creek mile (OCM) 0.68; Appendix C-5) was better than upstream at Ollis Creek Station 6 (OCM 4.15; Appendix C-6). This was due in part to greater distance of Station 1 from strip mining activity and two reservoirs between the stations that serve as settling basins for acid mine drainage products.

Water Quality--Reservoirs

Streams from both mined and unmined areas drain into Ollis Creek Reservoir 2 (OCM 3.37). This reservoir was directly impacted by strip mine activity. Mean values for samples at the surface and 1 ft above bottom (denoted as 9.1 m or 30 ft) were similar for pH, total acidity, total alkalinity, manganese, and sulfate (Appendix C-7). However, iron and turbidity were greater from bottom samples than in those taken at the surface.

Ollis Creek Reservoir 1 (OCM 0.78) is downstream from Reservoir 2 and receives water from the upper reservoir plus additional runoff from unmined watersheds. From August 1975 through July 1980, Reservoir 1 had slightly higher pH (Appendix C-7) than the upper reservoir (5.7 compared with 5.1). As expected, the buffering capacity (total alkalinity) was higher at Reservoir 1, with other water quality parameters (e.g., metals) lower in value. Mean values for pH, manganese, and sulfate in Reservoir 1 were similar at the surface and 1 ft above bottom (denoted as 6.1 m or 20 ft). Surface values for turbidity, total alkalinity, total acidity, and iron were lower than those from bottom.

Aquatic Macroinvertebrates

Streams--Response of aquatic macroinvertebrate communities in the Ollis Creek watershed to mining and reclamation activities appears to have been a function of the extent and severity of watershed disturbance, proximity of the receiving streams to toxic spoils, and the timing and effectiveness of intensive remedial reclamation procedures. The impact of unsuccessful conventional reclamation on diversity and standing crop of macroinvertebrate fauna in Ollis Creek and its tributaries was severe (Appendices D-1 and D-2). Except for Thompson Creek, recovery has been slow and limited.

Thompson Creek faunal recovery was probably best reflected by the increase in total taxa from 13 collected during mining (1970-1972) to 33 collected after remedial treatment (Appendix D-3). Mean number of individuals increased from 8.5 per ft^2 during remedial treatment to 29 per ft^2 by 1980 (Appendix D-4). The rate of recovery accelerated during 1976 due in large part to increases in dipteran taxa and numbers. However, from 1977 through July 1980 the community structure in Thompson Creek revealed significant decreases in dipterans and increases in numbers of plecopterans (stoneflies) and trichopterans (caddisflies) (Figure 9). The more rapid and complete recovery of Thompson Creek fauna was probably due at least in part to the fact that the Thompson Creek watershed was the first to receive remedial reclamation (fall 1974 through winter 1976).

Unnamed Tributary showed no trends of macroinvertebrate recovery through time (Figure 10). During the first year of remedial treatment (1976), there was a mean of three taxa and three individuals per ft^2, and this increased to only four taxa and four individuals by 1980 (Appendices D-4 and D-5). The lack of response to remedial treatment was attributed to fluctuating water quality, which did improve. However, conditions continued to exceed EPA water quality limits and tolerance levels of the native biotic assemblages. New species are unlikely to invade this area unless water quality stabilizes and concentrations of iron and manganese are greatly reduced.

The lesser impact of initial mining and conventional reclamation activities on the Laurel Branch aquatic macroinvertebrate community was related to the small proportion of watershed disturbed by mining activities. Although mean numbers per ft^2 were similar to Ollis Creek proper and other tributaries, total taxa and species diversity per sample date were significantly greater (Appendix D-2). Total taxa and diversity during 1978 increased from 28.0 and 2.6, respectively, to 38.0 and 3.5, respectively, during 1979. This relatively late increase corresponded to the time Laurel Branch watershed received intensive land treatment (spring 1977 through winter 1978).

Bottom fauna in mainstream Ollis Creek showed a very modest and overall slow rate of recovery. Although the total number of taxa collected at stations in Ollis Creek increased after the initial decrease due to mining, recovery from 1975 through 1980 was minimal (Appendices D-4 and D-5).

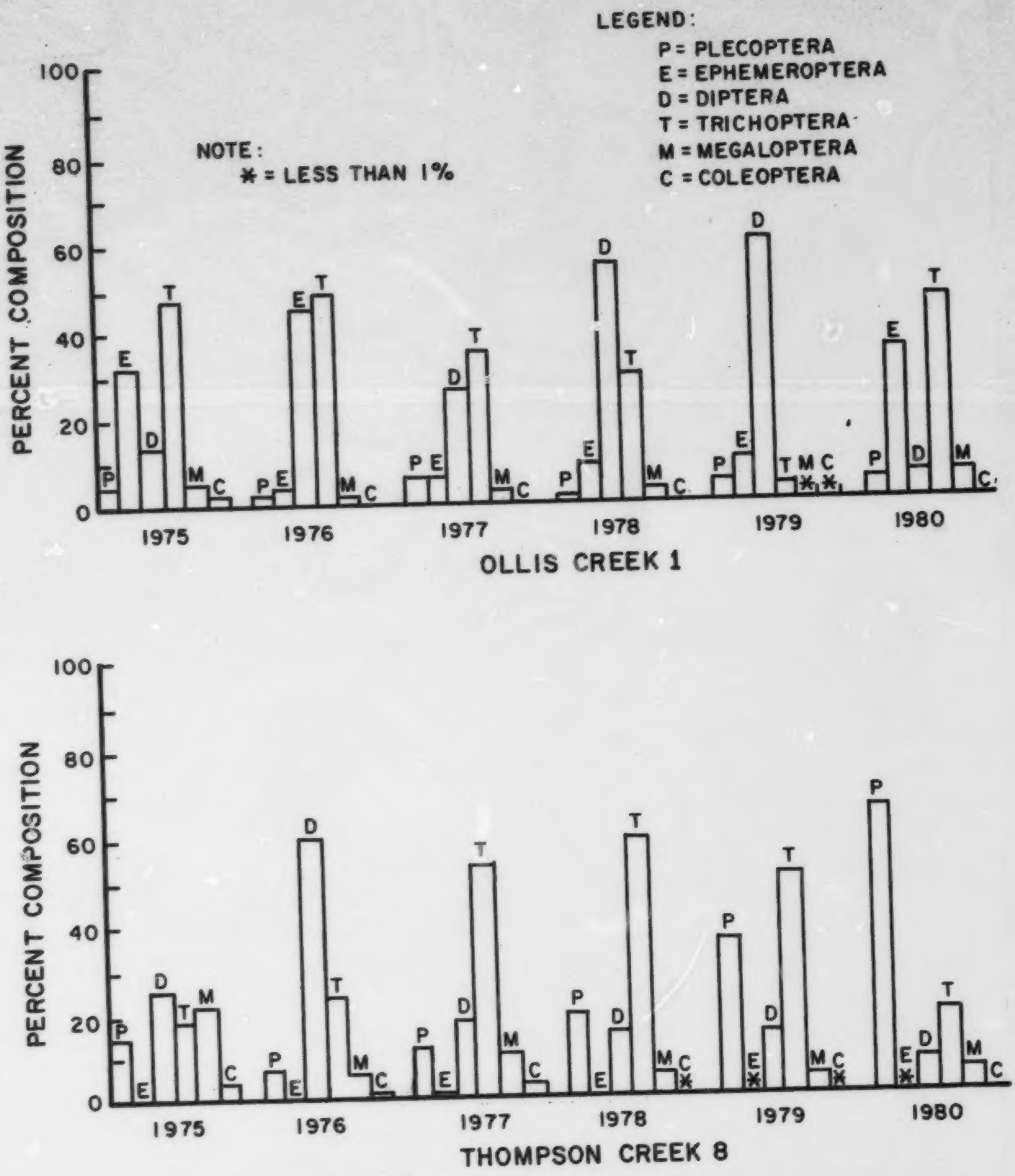

Figure 9. Benthic Community Structure per Year in Ollis Creek 1 and Thompson Creek 8 From August 1975 to July 1980

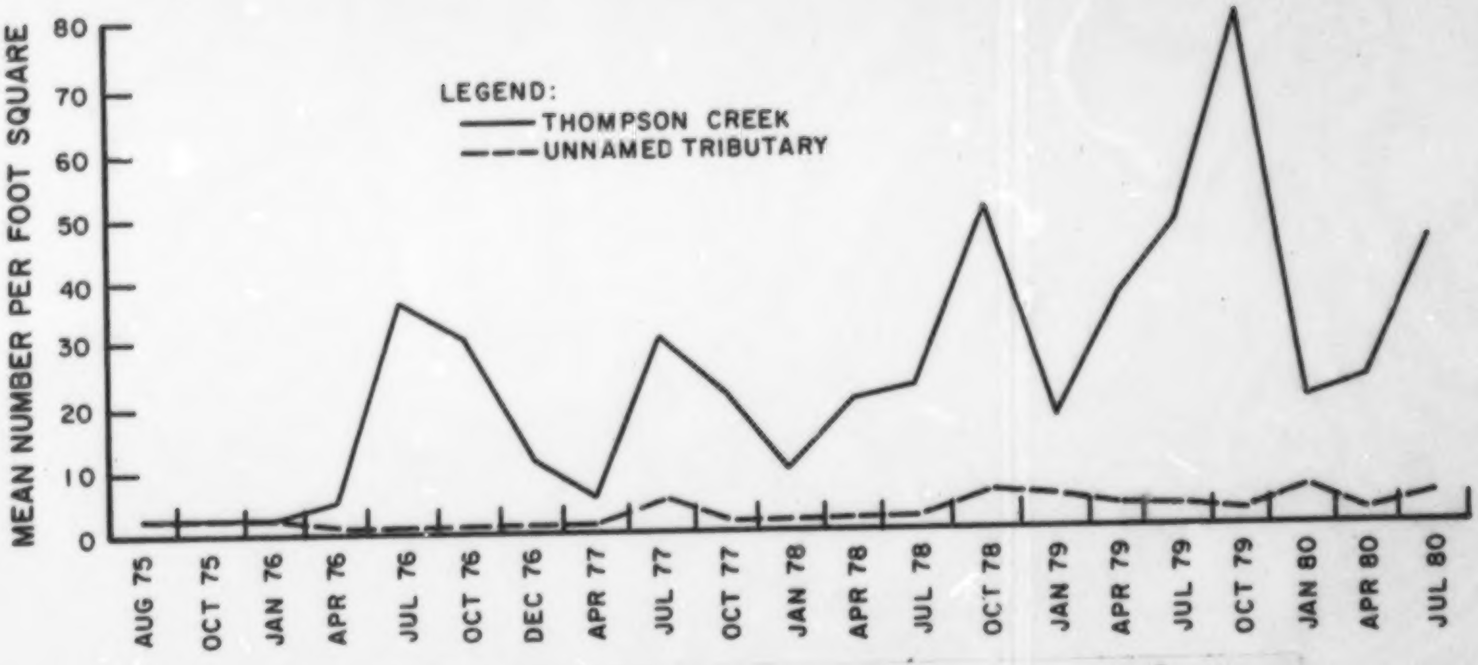

Figure 10. Mean Numbers of Aquatic Macroinvertebrates (1 ft^2 Surber) From Thompson Creek and Unnamed Tributary

At the onset of remedial treatment (August 1975), there was a mean of 20 macroinvertebrates per ft^2 and an average of 6 taxa at Station 1. At the end of posttreatment monitoring (July 1980) there was a mean standing crop of 26 organisms per ft^2 encompassing 10 taxa. The benthic faunal community at Station 1 was dominated by trichopterans and ephemeropterans during 1975 and 1976, but dipterans increased significantly from 1977 through 1979. In 1980 trichopterans and ephemeropterans increased and resumed dominance.

Recovery patterns at Ollis Creek Stations 2, 3, and 6 were very similar to Ollis Creek Station 1 (Appendix D-2). Of all Ollis Creek stations, Station 3 had the least response. Numbers of taxa, standing crop, and diversity indices were consistently lower than other Ollis Creek stations. Station 3 was immediately below the Reservoir 2 dam. In wet seasons, water plummeting over the dam kept substrate scoured, while in dry seasons minimal flow was passed through the dam, leaving much of the substrate exposed to drying. These fluctuating habitat conditions were more responsible for the decreased aquatic communities at Station 3 than degraded water quality.

Reservoirs--A total of 43 macroinvertebrate species was identified (Appendix D-6) from Reservoir 1 in surveys performed in the reservoir from March to September 1977. In addition, three frogs (Rana catesbeiana, Rana pipiens, and Chelydra serpentina) and two salamanders (Notophthalmus viridescens and Desmognathus sp.) were collected in qualitative samples.

Depth and the presence of seeps or creeks were variables that determined macroinvertebrate species distribution in May 1977 quantitative samples. Dredge samples taken in less than 1 m contained an average of 7 taxa and 22.3 total individuals. Dredge samples taken between 2 and 3 m contained an average of 4 taxa, totaling 37.8 individuals. In samples taken greater than 3 m, an average of 2 taxa, totaling 6.4 individuals, was present.

Community structure varied considerably with depth. In shallow areas (less than 1 m), hemipterans, trichopterans, and odonates were the most numerous taxa. If a spring or creek mouth was located nearby, then isopods, ephemeropterans, and megalopterans were present. In slightly deeper water (2 to 3 m), dipterans, coleopterans, and Hexagenia were most numerous. In samples greater than 3 m, oligochaetes and dipterans were virtually the only species present.

There was no significant difference (at the 0.05 probability level) in diversity or average numbers present between samples taken at the dam and samples taken in the old creek channel at the upper end of the reservoir. Samples at both locations were greater than 3 m depth. Thus it appears that any upstream sediment or water quality problems have not altered aquatic macroinvertebrate communities in this reservoir. Productivity was generally good, with a variety of species normally associated with lentic habitats. Species present in the reservoir were a possible source for natural colonization of upstream areas since several species collected also live in stream pools. In 1979 and 1980, Pseudocleon, present in Reservoir 1 in 1977, was recorded upstream for the first time since mining, indicating an increase in distribution had begun with improved water quality upstream.

Fish

Streams--Species collected from Ollis Creek and its tributary streams during mining and conventional reclamation (1970-1971) and those collected since intensive remedial land treatment (1975 through July 1980) are listed in Appendix E-1. Numbers and weights of fish collected from Ollis Creek are listed in Appendix E-2. As stated in the baseline report by Zarger et al. (1979), data indicate a general decline in numbers of fish species (from seven during mining to four during remedial treatment). Of the six species collected during this study, four (white crappie, emerald shiner, white sucker, and bluegill) were restricted to the Ollis Creek reservoirs.

No fish were taken from Thompson Creek, Yellow Branch, and Unnamed Tributary from August 1975 through July 1980. In contrast, creek chubs were collected consistently from April 1978 from Laurel Branch. The presence of creek chubs in Laurel Branch in 1978 coincided with completion of reclamation in this watershed. Their presence in April 1978 was probably the result of movement from the reservoir into streams for spawning. Creek chubs were not regularly collected in Laurel Branch until 1979. Between 1978 and 1979 there were major changes in pH and manganese in Laurel Branch.

Of seven species of fish collected from Ollis Creek during the mining period (1970-1972), four species remained; however, only the creek chub continued to exist in relative abundance. No significant recovery patterns were discernible for this species from the low numbers collected. The failure of previously occurring species to recolonize these streams might have been due to migration barriers (dams) as well as residual stresses from incompletely reclaimed toxic mine spoils.

Reservoirs--In April 1977, gill and hoop nets were set in Reservoir 1 to assess the diversity and relative abundance of fish species. Only white suckers were collected in gill nets and 94 percent of all white suckers were in nets set along the steep right bank. An average of 9.5 white suckers were caught per net night. One creek chub was collected from one of four hoop nets set on the shallow left bank.

It was decided these samples were not representative of the fish community present. Snapping turtles damaged a high percentage of individuals in the nets and perhaps removed a significant portion. A large population of turtles was present in the lake because 11 individuals were collected in gill nets. Male and female white suckers were ripe and obviously congregating prior to spawning. The numbers collected and the resulting ratio to other species were thought not to be representative of actual occurrence.

In September 1977, gill nets were set in Reservoir 1 to determine species present. Four species (creek chubs, white suckers, bluegill, and white crappie) were present in the reservoir. Of the 44 total individuals, white crappie were 2 percent, white sucker 17 percent, creek chub 20 percent, and bluegill 61 percent. Juvenile bluegill and creek chubs were collected from the shallow left bank by seining. Adults were not collected in this shallow area by nets, which was surprising due to the abundance of potential food organisms in this area. Bluegills were most abundant in the old creek channel at the upper end of the reservoir. White sucker and creek chubs were collected in water greater than 2 m in depth but not associated with a particular habitat.

Fish stocks were not sampled in Reservoir 2; however, bluegill were seen at the dam, and creek chubs were collected at the juncture of Laurel Branch with this reservoir. The presence of fish indicated that water quality has significantly improved from 1972 when acid mine drainage caused a large fish kill in both Reservoirs 1 and 2.

Comparison With a Reference Stream

Water quality--Since both Ollis (mined) and No Business Creek (unmined) watersheds have similar geology and both streams are naturally soft water, they were compared to determine significant changes in water quality as a result of strip mining. Selected water quality parameters (Appendix C-8) from downstream (Ollis Creek Station 1) and upstream (Thompson Creek, Station 8) stations in a mined watershed were compared to similar stations in an unmined watershed (No Business Creek, Stations 1 and 3) using a paired Student's "t" test (Appendix C-9).

Results of the paired "t" test showed significant differences in all water quality parameters tested. The pH values were found to be significantly different at the 0.05 probability level, while sulfate, iron, and manganese were found to be significantly different at the 0.01 probability level in tests between mined and unmined downstream stations. Both pH value and sulfate concentrations were found to be significantly different at the 0.01 probability level in tests between mined and unmined upstream stations. Water quality in Ollis Creek from headwaters to the lower reaches of this stream clearly had been impacted by acid mine drainage.

In order to determine if any significant changes in water quality at Ollis Creek occurred since January 1976 (during remedial treatment and post reclamation periods), differences in some water quality parameters indicative of acid mine drainage were compared at quarterly intervals from lower Ollis Creek (Station 1) with the control (unmined) stream.

A comparison through time showed that differences in pH levels between the two streams decreased (Figure 11), but not enough to be significant in a statistical sense ($b = 0.39$; $Pr > 0.05$). Data indicated that pH differences between Ollis and No Business Creeks decreased until 1978 but followed an annual cyclic pattern from July 1978, probably related to surface runoff patterns.

The difference in sulfate concentrations between Ollis and No Business Creeks is plotted in Figure 12. With a few exceptions there were differences between sulfate concentrations in the two streams from January 1976 through July 1980. There was not a statistically significant change in the Ollis Creek sulfate concentration following remedial treatment ($b = 0.23$; $Pr > 0.05$); however, Figure 12 reveals that a slight decline in sulfate levels occurred during the period January 1976 through July 1980 (remedial treatment and postreclamation periods).

The iron concentration at the lower Ollis Creek station improved significantly (declined in concentration) from January 1976 through July 1980

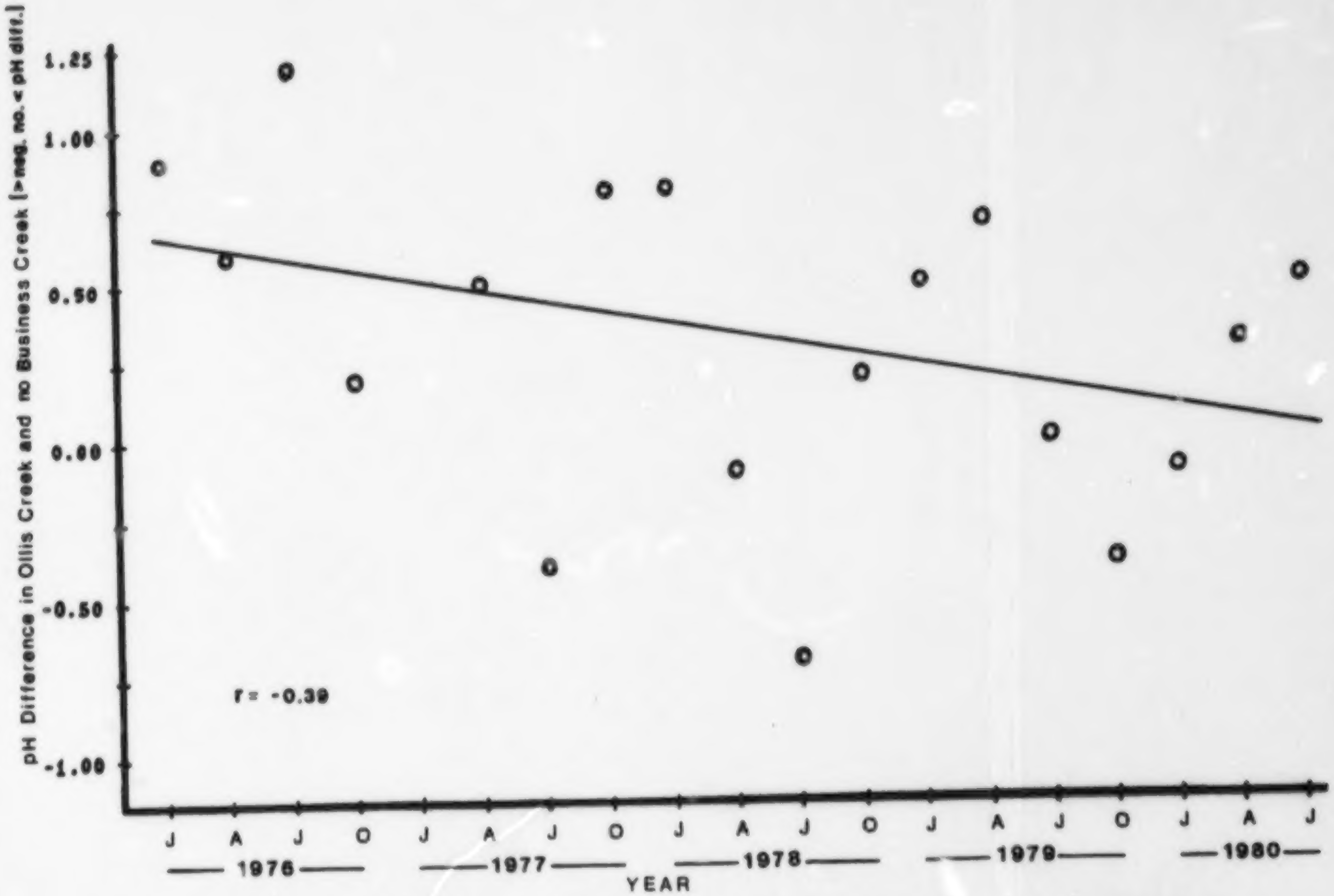

Figure 11. Changes in pH Through Time (1976 to July 1980) Based on Difference Between Sample Site Affected by Mining (Ollis Creek, Station 1) as Compared to Sample Unaffected by Mining (No Business Creek, Station 1)

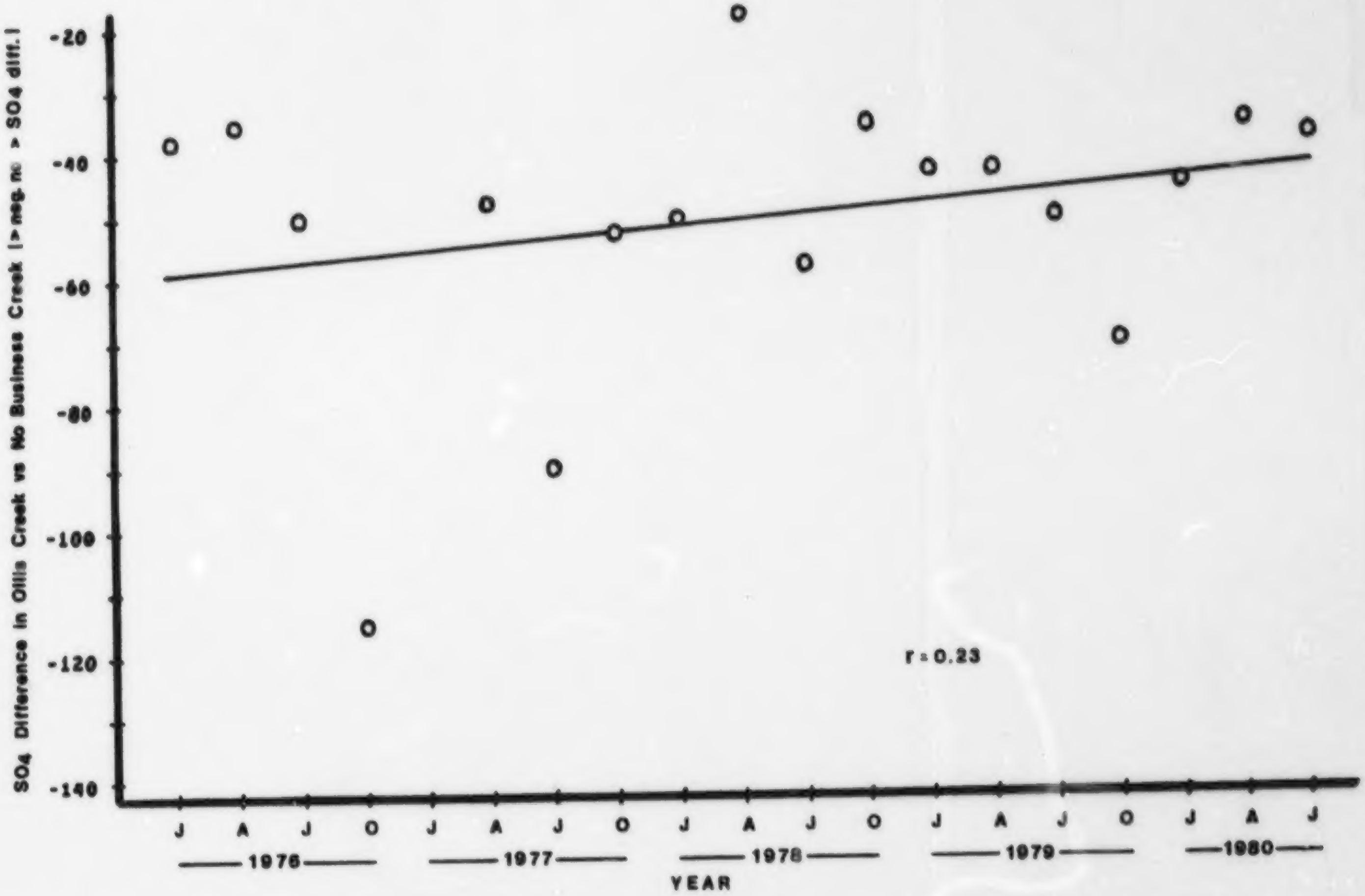

Figure 12. Changes in Sulfate (SO_4) Concentration Through Time (1976 to July 1980) Based on Difference Between Sample Site Affected by Mining (Ollis Creek, Station 1) as Compared to Sample Unaffected by Mining (No Business Creek, Station 1)

($b = 0.53$; $Pr < 0.05$). Differences in iron concentrations between lower Ollis Creek and No Business Creek continued to decrease through time (Figure 13). A study of strip mining effects on water quality in streams in eastern Kentucky (Dyer and Curtis 1977) found iron and manganese levels increased during and immediately after mining and then returned to normal within about one year after cessation of mining. Recovery in the Ollis Creek watershed was accelerated by remedial reclamation; however, the system still did not return to premining conditions. Soluble iron concentrations were inversely proportional to pH levels. A decrease in iron concentrations should correspond with pH recovery (neutrality) in Ollis Creek.

Manganese declined in concentration in Ollis Creek during and after remedial reclamation (Figure 14), but the decrease was not significant ($b = 0.32$; $Pr < 0.05$).

Aquatic macroinvertebrates--Comparisons of aquatic macroinvertebrates collected from Ollis and Thompson Creeks to corresponding stations on No Business Creek were made to determine differences in the biota and thus assess recovery during intensive remedial reclamation of the Ollis Creek watershed. Significant differences ($Pr < 0.01$) in both standing crop (mean numbers) and total taxa were found between upper and lower Ollis Creek stations compared to those at No Business Creek (Appendix D-7 and Figure 15). Mean numbers (Appendix D-8) increased throughout the study period. Mean numbers in Thompson Creek exceeded mean numbers in No Business Creek on some dates. However, there were still relatively large seasonal fluctuations in Thompson Creek indicative of community instability.

Compared with No Business Creek (Appendix D-8) Ollis Creek and its tributaries showed only slight increases in total taxa, numbers of organisms per ft^2 and species diversity since intensive remedial treatment began. Total numbers of aquatic invertebrate taxa remained fairly constant through time in both Ollis Creek and its tributaries. Samples from No Business Creek on the average yielded twice the number of taxa and a higher diversity than comparable samples from Ollis Creek and its tributaries. The total number of organisms collected per ft^2 was usually about three times greater at No Business Creek than for either Ollis Creek or its tributaries. Thus remedial treatments had not erased previous impacts to aquatic communities in the Ollis Creek watershed by 1980.

Fish--Six species were collected in Ollis Creek, while eight species were collected from No Business Creek (Appendix E-3). Creek chubs were the most abundant species in both streams (Appendices E-2 and E-4). White crappie, emerald shiner, and bluegill were only collected in Ollis Creek reservoirs, while stoneroller, bluntnose minnow, blacknose dace, stripetail darter, and arrow darter were collected only in No Business Creek. White suckers and northern hog suckers, although collected from both Ollis and No Business Creeks, were taken in only one sample from each stream.

Total fish biomass (weight) collected per stream per sample period (1975 through July 1980) was 122.1 g in Ollis Creek compared with 2,219.4 g in No Business Creek (Appendices E-2 and E-4). This difference was significant. Differential land use of the watersheds, size of the two streams, and blockage of immigration by the reservoirs on Ollis Creek have contributed to the species differences in the two streams (Zarger et al. 1979).

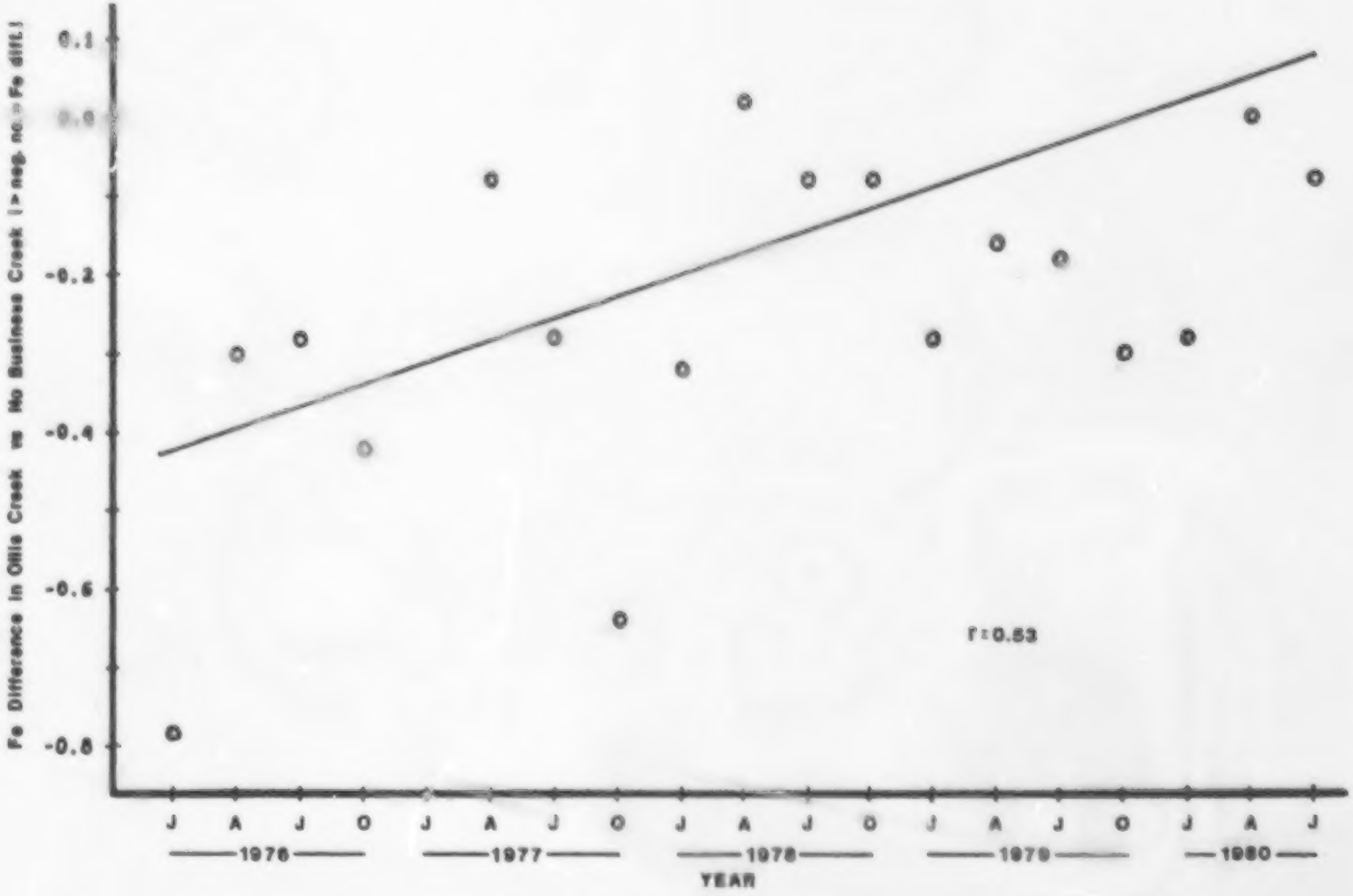

Figure 13. Changes in Iron (Fe) Concentration Through Time (1976 to July 1980) Based on Difference Between Sample Site Affected by Mining (Ollis Creek, Station 1) as Compared to Sample Unaffected by Mining (No Business Creek, Station 1)

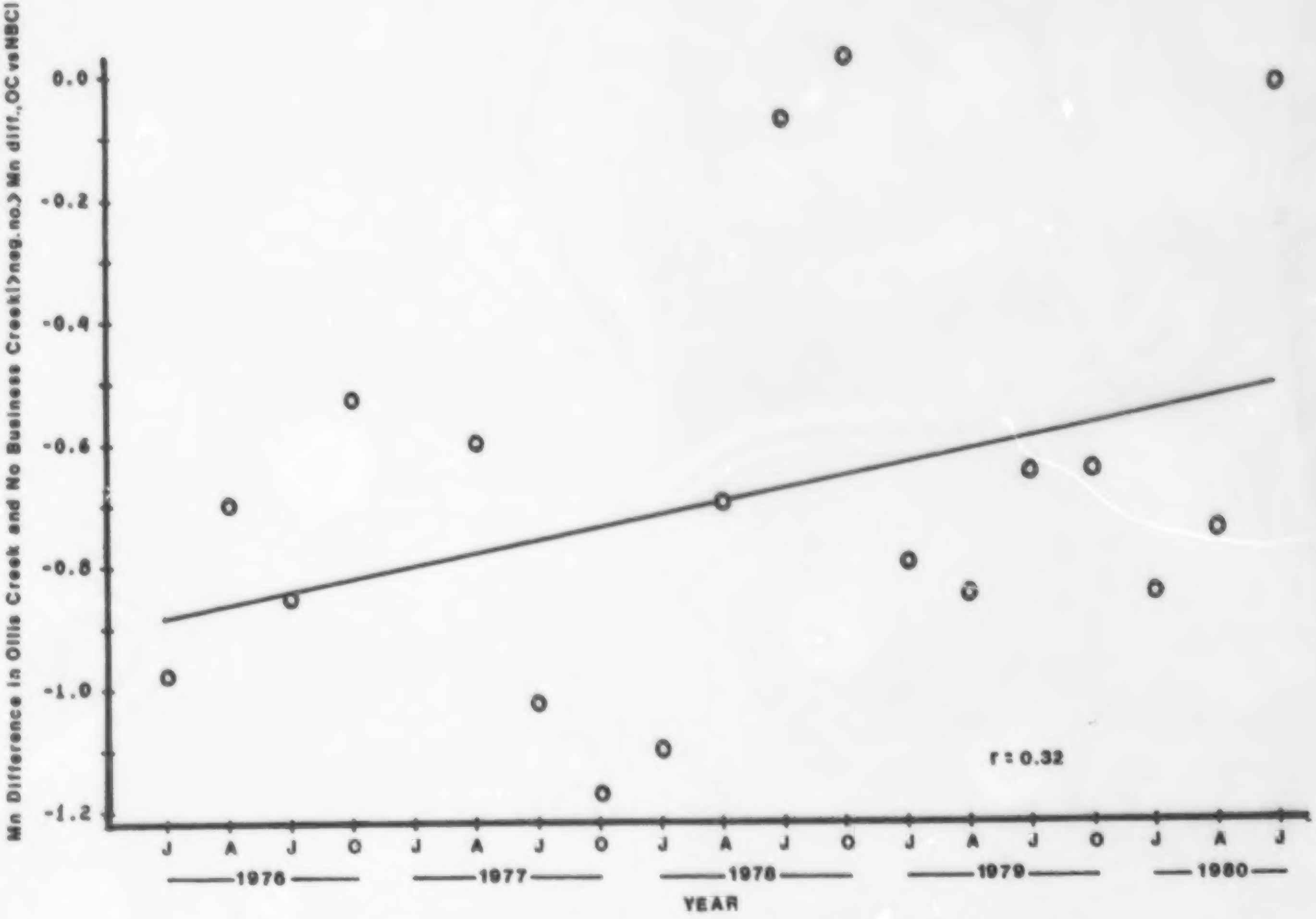

Figure 14. Changes in Manganese (Mn) Concentration Through Time (1976 to July 1980) Based on Difference Between Sample Site Affected by Mining (Ollis Creek, Station 1) as Compared to Sample Unaffected by Mining (No Business Creek, Station 1)

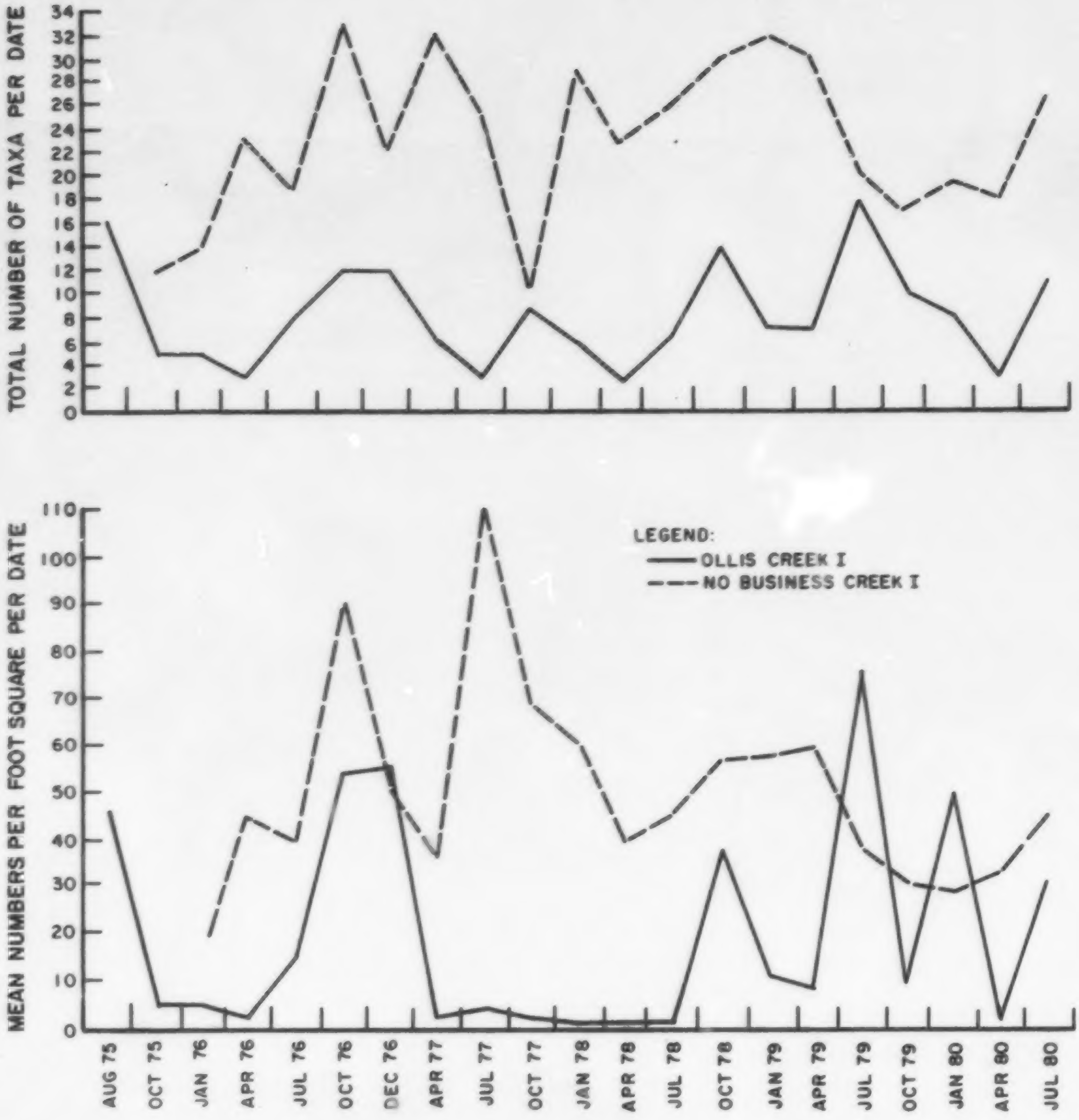

Figure 15. Mean Number of Aquatic Macroinvertebrates and Total Taxa From Ollis Creek Station 1 (Mined Watershed) and No Business Creek, Station 1 (Unmined Watershed)

Except for creek chubs, northern hog sucker, and white suckers, there appeared to be no stream-associated fish species living in the Ollis Creek reservoirs, which might serve to recolonize stream sections above the reservoirs. Stocking efforts will be required to return additional native fish species to this drainage. As water quality improves to acceptable limits, the likelihood of success of any attempted transplants increases.

The Tennessee Wildlife Resources Agency (TWRA) began restocking Ollis Creek Reservoirs 1 and 2 in 1979. No assessment of stocking success (e.g., growth rates) for these game species was performed.

Bioaccumulation of Selected Heavy Metals by Fish and Turtles in Ollis Creek Reservoir 1

In a cooperative effort with The University of Tennessee in spring 1977, TVA surveyed fish and turtles in water bodies receiving mine runoff for metal accumulation. The most common of these in Ollis Creek Reservoir 1, white sucker, bluegill, and snapping turtle, were analyzed for copper, cadmium, and lead.

White sucker, whose food habits include consumption of detrital material, could be expected to have the highest metal accumulation. The results are summarized in Table 17.

TABLE 17. CONCENTRATION OF COPPER, CADMIUM, AND LEAD IN THREE WHITE SUCKERS COLLECTED FROM OLLIS CREEK RESERVOIR 1 IN APRIL 1977

	Copper (ppb)		Cadmium (ppb)		Lead (ppb)	
Tissue	Mean	Range	Mean	Range	Mean	Range
Muscle	0.66	0.2-1.1	*	*	0.2	0.0-0.6
Kidney	4.00	4.0-4.0	3.8	3.3-4.0	0.2	0.1-0.3
Brain	1.40	0.2-2.0	3.5	0.4-5.1	0.2	0.1-0.4
Gill	3.50	2.2-8.7	4.3	2.9-6.7	0.3	0.2-0.5

* Not analyzed.

In general, copper, cadmium, and lead concentrations were highest in kidneys or gills. The kidneys and gills both serve as excretory organs, with the gills serving as active and passive transport sites for the metabolic regulation of water, salts, and waste products. The higher concentration of metals in these tissues indicated metabolic regulation rather than the presence of high concentrations in the body.

Bluegills, whose insectivorous food habits include terrestrial sources, could be expected to have lower concentrations of metal. Results for this species are summarized in Table 18.

TABLE 18. CONCENTRATION OF COPPER AND CADMIUM IN THREE BLUEGILL COLLECTED FROM OLLIS CREEK RESERVOIR 1 IN APRIL 1977

Tissue	Copper (ppb)		Cadmium (ppb)	
	Mean	Range	Mean	Range
Muscle	0.42	0.2-0.6	*	*
Kidney	3.11	1.7-3.7	2.58	1.8-3.2
Brain	0.58	0.5-0.6	*	*
Gill	4.33	1.8-5.0	4.00	4.0-4.0

* Not analyzed.

Metal concentration trends in bluegill were similar to that in white sucker, however, mean concentrations were generally less. Copper concentrations in the gills and kidneys were as much as tenfold greater than in other tissues. The concentrations point to the execretory function of these structures as well as their obvious effectiveness in regulating body accumulation of metals.

Snapping turtles, whose size, omnivorous diet, and voracious appetite place them at the top of the food chain in Ollis Creek Reservoir 1, should have had the highest metal accumulations. One individual, with three replicate samples, was utilized for analysis. The results are summarized in Table 19.

TABLE 19. CONCENTRATION OF COPPER, CADMIUM, AND LEAD IN A SNAPPING TURTLE (THREE REPLICATE SAMPLES) COLLECTED FROM OLLIS CREEK RESERVOIR 1 IN APRIL 1977

Tissue	Copper (ppb)		Cadmium (ppb)		Lead (ppb)	
	Mean	Range	Mean	Range	Mean	Range
Liver	0.33	0.3-0.4	3.23	2.8-3.7	0.11	0.1-0.2
Brain	0.29	0.1-0.5	5.89	3.4-10.1	0.94	0.7-1.2
Muscle	0.08	0.0-0.2	1.68	0.4-4.0	0.31	0.0-2.0
Tendon	0.09	0.0-0.1	2.09	0.5-4.0	0.14	0.1-0.2
Heart	0.12	0.1-0.2	1.24	0.8-1.4	0.28	0.2-0.3

As in bluegill and white sucker, copper and lead concentrations were relatively low, while cadmium concentrations were relatively high. No pattern emerged for these three metals as to which tissues were most or least susceptible to accumulation; however, the brain had consistently high levels of each metal.

Due to a lack of supplemental funding, analyses were discontinued after this preliminary survey of metal accumulations.

SUMMARY

Water Quality

The baseline report documented an acid mine drainage problem throughout the entire length of Ollis Creek. Several water quality parameters indicative of acid mine drainage (pH, SO_4, Fe, and Mn) were utilized to assess the value of remedial treatments. Water quality improvement was examined for one monitoring station in each of the three land treatment sectors.

Thompson Creek--Sector 2, which includes the Thompson Creek watershed, received remedial treatments from fall 1974 through 1976. Thompson Creek was monitored to determine response of several water quality parameters to these initial treatments. Between 1975 and 1978 (during remedial treatments) pH increased. Sulfate, iron, and manganese fluctuated but showed no trend. In contrast, between 1978 and 1980 there was a significant decrease of approximately 50 percent in the average annual concentrations of iron, sulfate, and manganese. Remedial treatments were completed in fall 1976; therefore, there was a 2-year lag before the effects of reclamation activities were detectable as an appreciable improvement in water quality.

As of 1980, it had been 8 years since the cessation of mining activities in this watershed. Iron has decreased to acceptable levels but sulfate and manganese has remained elevated relative to EPA standards. Estimates of recovery to standards or premining concentrations were calculated utilizing exponential curve fitting on both the running average of quarterly parameter concentrations and the annual average of data from 1978 through 1980 (Table 20). The running average, while leveling high and low concentrations, is conservative. Assuming recovery continues at the same rate, it is estimated from the quarterly data that sulfates will reach premining levels in an additional 17 years, while an additional 6 years will be required for manganese to reach acceptable levels. Using the average annual recovery rate (which remains variable, thus retarding integrated recovery), the system is estimated to require an additional 10 years for sulfate and 3 years for manganese to reach these same levels.

Unnamed Tributary and Ollis Creek Station 6--Sector 3, which includes Unnamed Tributary and Ollis Creek Station 6, received remedial treatments from 1975 through 1977. Water quality, particularly at Unnamed Tributary, had elevated concentrations of sulfate, iron, and manganese. Between 1975 and 1977, average pH increased but still fluctuated to unacceptably low levels. Only in 1980 were pH, sulfate, iron, and manganese stabilizing toward acceptable levels. If Unnamed Tributary was experiencing a lag between remedial treatments and water quality improvement similar to Thompson Creek's, then 1980 may have been the first year of noticeable improvement in water quality parameter levels. Because monitoring was discontinued in 1980, this cannot be substantiated.

TABLE 20. EXPONENTIAL CURVE FITTING SUMMARIES FOR IRON, MANGANESE, AND SULFATE AT THOMPSON CREEK, UNNAMED TRIBUTARY AND OLLIS CREEK STATION 1

		Thompson Creek after reclamation (post 1977)		Unnamed Tributary during and after reclamation (post 1977)		Ollis Creek Station 1 during and after reclamation (post 1976)	
		Running mean	Yearly average	Running mean	Yearly average	Running mean	Yearly average
	Y^2	0.91	0.97	0.74	0.46	0.50	0.66
Fe	Equation	$Y=0.46e^{-0.3X}$	$Y=0.68e^{-0.54X}$	$Y=13.3e^{-0.07X}$	$Y=4.9e^{-0.21X}$	$Y=0.41e^{-0.06X}$	$Y=0.45e^{-0.22X}$
Years to reach	0.3 ppm* 1.0 ppm†	Below std	Below std	82 44	13 7	Below std	Below std
	Y^2	0.94	0.93	0.22	0.89	0.32	0.71
Mn	Equation	$Y=2.72e^{-0.07X}$	$Y=4.19e^{-0.45X}$	$Y=31.47e^{-0.02X}$	$Y=20.90e^{-0.18X}$	$Y=0.96e^{-0.04X}$	$Y=1.04e^{-0.15X}$
Years to reach	0.5 ppm†	6	3	59	21	4	5
	Y^2	0.48	0.94	0.71	0.98	0.20	0.58
SO_4	Equation	$Y=98.26e^{-0.03X}$	$Y=127.86e^{-0.24X}$	$Y=668.3e^{-0.05X}$	$Y=669.9e^{-0.19X}$	$Y=63.5e^{-0.02X}$	$Y=90.06e^{-0.18X}$
Years to reach	20 ppm‡	17	10	17	21	20	11

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* EPA 1976.

† EPA 1976. Criteria for domestic water supplies.

‡ Calculations based on a premining concentration of 20 ppm.

An estimate of recovery to standards or premining concentrations has been calculated utilizing exponential curve fitting on both the running average of quarterly parameter concentrations and the annual average of data from 1978 through 1980 (Table 20). Using the quarterly data and assuming recovery continues at the same rate, an additional 17 years is estimated for sulfate to reach premining levels, an additional 58 years for manganese, and 82 years for iron to recede to levels approximating EPA standards. Using average annual data, the system is estimated to require an additional 21 years for sulfate, 21 years for manganese, and 44 years for iron to reach these same levels. Although the recovery rate after remedial reclamation for iron, manganese, and sulfate was similar at Unnamed Tributary and Thompson Creek, the greater initial concentrations in Unnamed Tributary will require a much greater period for recovery to water quality standard levels.

Laurel Branch and Ollis Creek Station 1--Sector 4, which includes Laurel Branch and Ollis Creek Station 1, received remedial treatments from 1976 to 1978. These stations have shown modest increases in pH and decreases in iron and sulfate since remedial reclamation efforts. Response of Ollis Creek Station 1 to remedial treatments was more positive than that of Thompson Creek in Sector 2, yielding a 50 percent decrease in iron and sulfate between 1977 and 1978 and smaller decreases in manganese concentrations. Since Station 1 was downstream of all early mining and reclamation efforts, it was chosen for further examination to determine total system recovery. Although water quality improvement began relatively soon after treatment, water quality did not begin stable improvement until 1978, with a time lag similar to Thompson Creek's.

An estimate of recovery to standards of premining concentrations was calculated utilizing exponential curve fitting on both the running average of quarterly parameter concentrations and the annual average data from 1978 through 1980 (Table 20). Assuming current recovery rates, the quarterly data in running averages predict an additional 20 years would be required for sulfate and 4 years for manganese to return to acceptable levels. Iron has declined to levels consistent with EPA standards for domestic water supplies. Estimates using the average annual data predict this system would require an additional 11 years for sulfate and manganese to recede to these same levels. These recovery rates are very similar to those at Thompson Creek.

The lag time for system response is not unique. Dyer and Curtis (1977) reported a similar response after mining. In the Ollis Creek watershed, liming and fertilizing resulted in an immediate but unstable response of water quality parameters. In some cases a slight degradation of these parameters followed. Within 1 or 2 years after reclamation, water quality parameter minima, maxima, and average values began to change. The results of this study demonstrate that a short-term monitoring study (1 year after the end of treatments) would not have shown the response of this system to treatment. In fact, this 5-year study was not sufficiently long to document recovery to premining conditions; however, recovery trends are clear at this point.

Aquatic Macroinvertebrates

Minear et al. (1978) analyzed recovery trends for aquatic macroinvertebrate communities in streams affected by surface mining by plotting species diversity and number of taxa and individuals against time. They found all these parameters decreased after mining, reaching minimum levels 4 to 6 years after mining and then increasing gradually to predisturbance levels 22 years later. Inspection of Ollis Creek data shows number of taxa and standing crops declined after mining and conventional reclamation and, following the application of intensive remedial land treatment, a trend of slow and limited recovery (Appendix D-2).

Overall, Thompson Creek exhibited the best recovery response, probably because of improved water quality attributable to the timing (first to receive intensive remedial land treatment) and effectiveness of land stabilization treatment within that watershed. Despite improvements, some species were still absent from Thompson Creek when compared to No Business Creek, an undisturbed stream.

Aquatic macroinvertebrates in Laurel Branch were not as severely affected as other tributary stations because of the limited mining done within its watershed. Thus aquatic macroinvertebrate communities at this station more closely resembled communities collected from No Business Creek.

No major differences were apparent for comparisons of number of taxa, standing crop, and diversity indices from stations on Ollis Creek proper with stations from its more severely affected tributaries. The only stations where numerical or diversity increases occurred were those with large water quality improvement (Thompson Creek and Laurel Branch). Even at these stations, species present were those which tend to be relatively tolerant of pollution. As water quality improves and habitats change, these tolerant species will probably be replaced by less tolerant species. With time the fauna of Ollis Creek watershed may approach communities present prior to mining or that in No Business Creek. Before this can occur, water quality must stabilize near EPA water quality standards. When such recovery occurs, recolonization can be expected to occur naturally from adjacent populations.

Thus from current water quality improvement trends, full macroinvertebrate recovery can be calculated to take, conservatively, an additional 20 to 82 years. Optimistically aquatic communities could take an additional 5 to 17 years to recover if seasonal variations decrease.

Fish

With the geochemistry of the watershed slightly acidic before disturbance, mining activities were responsible for reducing pH values well below the 6.5 to 9.0 pH range that EPA (1976) recognizes as productive for freshwater aquatic life. Highest pH values in Ollis Creek and its tributaries during remedial treatment remained below 6.0. Slow recolonization by fish may be expected until the pH increases above 5.5.

At the end of monitoring, creek chub was the only species common to both Ollis Creek and No Business Creek. The absence of several fish that previously occurred in flowing portions of Ollis Creek appears to have been due to the lack of stream species in Ollis Creek reservoirs which might have served as stream colonizers. Water quality conditions in the watershed apparently retard fish recolonization in Ollis Creek; otherwise, creek chubs, white suckers and hog suckers would have expanded throughout accessible Ollis Creek tributaries.

SECTION 4

RESERVOIR SEDIMENTATION

Measurements on the rate of sediment deposition in downstream Reservoir 2 (Figure 1) reflect the adverse conditions that resulted from the conventional mining and reclamation and subsequent improvement from remedial treatment. Table 21 summarizes reservoir sediment survey data taken annually from October 1970 through February 1981 by TVA's Division of Services and Field Operations.

TABLE 21. RECONNAISSANCE OF RESERVOIR SEDIMENT DEPOSITION

Survey date	Time since closure (yrs)	Sediment deposition		Cum. storage loss (pct)
		Period (m^3)	Cum. total (m^3)	
10-06-70	6.5	14,303	14,303	1.8
09-15-71	7.4	616	14,919	1.8
10-27-72	8.5	13,193	28,112	3.4
10-12-73	9.5	16,152	44,264	5.4
10-17-74	10.5	8,014	52,278	6.4
10-20-75	11.5	4,808	57,086	7.0
11-03-76	12.6	5,055	62,141	7.6
10-28-77	13.6	3,945	66,086	8.1
10-03-78	14.5	-1,233*	64,853	8.0
10-25-79	15.6	9,000	73,853	9.1
02-26-81	16.9	0	73,853	9.1

* Minus indicates negative sediment.

Original storage capacity of the 17-m high (55-ft) water reservoir was 815,013 m^3 (661 ac-ft). From closure of the dam in 1964 until October 1970, sediment deposition totaled 14,303 m^3 (12 ac-ft), resulting in a 6-year storage loss of 1.8 percent. Between October 1970 and October 1974, the period that encompassed the major mining and operator reclamation effort, sediment deposition totaled 37,975 m^3 (31 ac-ft). Reservoir storage loss for the 4-year period amounted to 4.6 percent and left a storage capacity of 762,735 m^3 (619 ac-ft).

The low rate of sediment deposition during the first full year of mining was attributed to the slow movement of sediment down the outslopes and into small drains below mined areas. In 1972 and 1973, with rainfall averaging some 45.7 cm (18 in.) above normal, this sediment, plus additional contributions, was deposited in the reservoir. Intense storms in the spring of these 2 years resulted in heavy washing of watershed logging roads and in washing out of small sediment traps in drains below mined areas. The rate of deposition in 1974 was less than half the rate of 1973 even though rainfall during the year was 189.5 cm (74.6 in.)--58.4 cm (23 in.) above normal.

Remedial reclamation was initiated in fall 1974 and continued through spring 1978 until all problem areas had been treated (Table 1). During these 4 years sediment deposition was one-third the amount that entered the reservoir during the previous 4 years. Sediment deposition from October 1974 to October 1978 was 12,575 m^3 (10 ac-ft) compared to the 37,975 m^3 (31 ac-ft) entering the reservoir between October 1970 and October 1974, although rainfall in the 1975 and 1976 survey years averaged 166.1 cm (65.4 in.)--35.5 cm (14 in.) above normal. However, rainfall during 1977 and 1978 was near normal. For the 4-year period reservoir storage loss amounted to 1.6 percent of original capacity.

Sediment deposition for the 1979 and 1980 survey years totaled 9,000 m^3 (7 ac-ft), resulting in a reservoir storage loss of 1.1 percent. Rainfall for the October 1978 to October 1979 measurement period was 160.8 cm (63.3 in.), 30.5 cm (12 in.) above normal. Rainfall between October 1979 and February 1981 was below normal, amounting to only 105.2 cm (41.4 in.).

Aside from the mining detailed in this report, other activities within the watershed undoubtedly contributed to the reservoir sedimentation problem, but their effects could not be differentiated. The number of dune buggies and 4-wheel drive recreational vehicles increased dramatically during the 1970's. Improved access to the area was an invitation to offroad vehicle enthusiasts to use portions of the mine in pursuit of their weekend hobby. Despite efforts by the private forest land manager to restrict and concentrate the offroad vehicle activity, control was difficult. Erosion and runoff from repeated vehicle use of newly revegetated mine slopes and benches were visibly striking. Other land disturbances in the late 1970's included extensive clearcutting of timbered areas, construction of a powerline to an underground mine and the operation, off Koppers property, of a "wildcat" surface mine. This disturbance was first noted in November 1979 aerial photography. Before regulatory authorities could stop the illegal operation in mid-1981, some 20 ha (50 ac) had been disturbed. While some distance from the main drainage, the operation had the potential for contributing to sediment buildup.

A positive influence on slowing surface mine runoff may have been the introduction of the beaver, Castor canadensis, to the watershed, also in the late 1970's. The first report on the transplant of beavers by the Tennessee Wildlife Resources Agency was in November 1979. By then the fur-bearing animals had become established at several locations and had produced offspring. Their influence on reducing reservoir sedimentation was probably neglible.

In summary, the average annual rate of sediment deposition was 2,384 m^3 (1.9 ac-ft) for the 6 years before mining and increased to 9,494 m^3 (7.7 ac-ft) during the 4 years of conventional mining and reclamation. In the ensuing 6-year period, which reflected results of the remedial treatment, the average annual rate dropped to 3,585 m^3 (2.9 ac-ft). No increase in sediment deposition was noted in survey data covering the period October 1979 through February 1981. Continued monitoring for several years would be desirable to ensure that erosion and runoff from the minesite have been arrested.

SECTION 5

SUMMARY AND CONCLUSIONS

BACKGROUND

This study evaluates early effects of selected remedial land treatments on ecosystem recovery of a forested watershed area impacted by surface mining. Some 162 ha (400 ac) within a 2,800 ha (11 mi^2) watershed in eastern Tennessee was mined between spring 1970 and spring 1972. The toxic nature of the spoil material associated with the coal seams was unknown to the mine operator. Pyritic materials (acid-producing shales) became mixed with the overburden, leaving a hostile environment for plant growth and development. Repeated attempts by the operator to revegetate the spoils by conventional measures proved unsuccessful. Two years after mining and reclamation, only 24 percent of the mined area had become stabilized. As a result of the barren spoils, siltation and acid mine drainage began to affect receiving stream quality and accelerate siltation in a city water supply reservoir. These impacts were noted from monitoring initiated at the onset of mining. Equally serious was the nonproductive state of the mined land area.

REMEDIAL TREATMENT

An intensive remedial land treatment developed for the essentially bare 125 ha (308 ac) was initiated in fall 1974. Remedial work was planned to complete vegetative establishment over 3 years by treating one-third of the affected area each year. The selected revegetation practices included both fall and spring treatments--heavily liming, disking, and seeding in the fall and overseeding the same area in the spring. Additionally, forest tree and wildlife shrub seedlings were planted the following season. Emphasis was on reestablishing an effective cover without accelerating the rate of reservoir sedimentation.

Ecological recovery analyses were related to four approximately equal land sectors--the mined area characterized as reclaimed (control) and three treatment sectors comprising the poorly revegetated problem sites. Annual vegetation inventories conducted from October 1975 through October 1980 documented plant establishment and growth. Small mammal and bird populations were censused twice annually to measure successional patterns. Aquatic systems evaluation involved sampling of the main drainage (Ollis Creek) and its tributaries for instream water quality conditions and the rate of recovery of macroinvertebrates and fish. Annual surveys measured rate of silt deposition in the reservoir.

RESULTS

Terrestrial Systems

Vegetation--As a result of the remedial treatments and invasion of naturally seeded species, herbaceous ground cover on the impacted minesite increased from 33 percent in fall 1975 to 78 percent in fall 1980. Naturally invading vegetation accounted for only 6 percent of the total cover in 1975, increasing to 21 percent in 1980. This increase in naturally invading species is attributed in part to the intensive site amelioration treatments that included liming and disking. The pH levels of treated areas slightly increased, contributing to revegetation success.

Spread of reclamation and naturally occurring revegetation on the control area that had been characterized as reclaimed in 1974 increased by 27 percent--from a total cover of 62 percent in 1975 to 89 percent in 1980. Similarly spread of revegetation on treated areas increased by 49 percent over the period--from 26 percent to 75 percent. After 5 years vegetative cover was well established on the minesite.

Over 75 species of herbaceous and woody plants were noted to be growing on the mined area during the 5 years. By 1980, 22 species occurring in 1975 were gone, while 21 not observed in 1975 later became established. The diversity and change are a positive indication of an early stage of ecological recovery.

The predominant species were those seeded or planted in the remedial reclamation effort. Kentucky-31 fescue was the predominant reclamation species and comprised 26 percent of the cover. Broomsedge was the predominant native species, with 7 percent cover. Virginia pine, autumn-olive, and naturally seeded red maple were the predominant woody plants in 1980.

Bird and small mammal populations--Breeding and wintering bird populations increased on all mine sectors, although increases by sectors were not uniform from year to year. Increases in the bird population were correlated with increases in the total vegetative cover, percentage of natural cover, percentage of forb cover, herbaceous height and volume, and the number of trees and shrubs. The bird population was negatively correlated with the percentage of revegetation cover and graminiferous cover. Winter birds had a preference for naturally occurring herbaceous vegetation.

Small mammal populations were highest during early years of the study, when there was an abundance of heavy-seeded grasses. The control sector, which had the most vegetation at start of the study and the highest diversity of microhabitats, had a more stable and more diverse population than did the other sectors.

Aquatic Systems

Instream water quality that had been degraded by mining began to improve 1 to 2 years following completion of remedial reclamation and was continuing to improve at termination of monitoring in 1980. Tributaries such as Thompson

Creek and Laurel Branch generally improved faster than mainstream Ollis Creek. Coinciding with quality improvement, aquatic macroinvertebrates increased in number and diversity with communities in Thompson Creek, numerically approaching populations in the control stream. Annual average physical/chemical conditions improved; however, this improvement was tempered by seasonal fluctuations, generally with maximum (for pH minimum) parameter levels during summer/fall low-flow conditions. This indicates that parameter increases normally related to surface flow and erosion have been controlled and that although ground water contamination may have been ameliorated, it has not been eliminated.

One stream, Unnamed Tributary, with perhaps the worst water quality prior to remedial reclamation, showed improvement in water quality, but an insignificant response of aquatic communities. In 1980 water quality still exceeded minimum standards but approached the quality found in Thompson Creek prior to 1975 remedial reclamation. Only a depauperate community of tolerant species still existed at Unnamed Tributary and perhaps was limited by relatively large cyclic seasonal fluctuations.

The most evident improvement in water quality was minimum and maximum pH, which appears to be associated with improved ground cover resulting from the remedial treatments. Among the other indicators of water quality conditions, two parameters--iron and manganese--require mention. Iron decreased in Thompson Creek and Ollis Creek Station 1 to meet criteria for domestic use. Manganese also decreased, but for it to reach premining levels at Station 1 will conservatively require from 4 to 5 additional years. In contrast, manganese recovery in Unnamed Tributary will require several decades.

Fish populations are present in the Ollis Creek drainage primarily in the downstream reservoirs. These fish utilize the flowing portions of the Ollis Creek tributaries periodically. Fish species are limited, and only the creek chub and white sucker exist in relative abundance.

Reservoir Sedimentation

The average annual rate of sediment deposition in the city water supply reservoir was 2,384 m^3 (1.9 ac-ft) for the 6 years before mining. The rate more than tripled during the 4 years of conventional mining and reclamation. In the ensuing 6-year period, which reflected results of the remedial treatment, the average annual rate decreased to 3,585 m^3 (2.9 ac-ft). No sediment deposition was noted in survey data covering the last year of monitoring, but rainfall was below normal for the year.

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APPENDIX A

(Supplemental Information on Vegetation)

TABLE A-1. PLANT SPECIES FOUND ON THE MINESITE

Common Name	Scientific Name
Grasses	
Barnyard grass*	*Echinochloa crusgalli* (L.) Beauv.
Broomsedge*	*Andropogon virginicus* L.
Crabgrass†	*Digitaria sanquinalis* Heist.
Fescue, Kentucky-31*	*Festuca arundinacea* Schreb., (var.)
Lovegrass, weeping*	*Eragrostis curvala* (Schrad.) Nees
Millet, foxtail*	*Setaria italica* (L.) Beauvois
Oatgrass, poverty†	*Danthonia* spp.
Orchard grass†	*Dactylis glomerata* L.
Panic grass*	*Panicum* spp.
Redtop grass†	*Agrostis alba* L.
Ryegrass, perennial‡	*Lolium perenne* L.
Switchgrass*	*Panicum virgatum* L.
Legumes	
Beggar-lice†	*Desmodium* spp.
Bushclover†	*Lespedeza violacea* (L.) Pers.
Clover, red‡	*Trifolium pratense* L.
Lespedeza, Kobe*	*Lespedeza striata* (Thunb.) H. & A. (var.)
Lespedeza, Korean*	*Lespedeza stipulacea* Maxim.
Lespedeza, sericea*	*Lespedeza cuneata* (Dumont) G. Don
Partridge-pea†	*Cassia fasciculata* Michx.
Sweetclover, yellow†	*Melilotus officinalis* (L.) Lam.
Sicklepod‡	*Cassia tora* L.
Composites	
Aster*	*Aster* spp.
Coreopsis*	*Coreopsis auriculata* Schkuhr & Hort.
Daisy, field‡	*Chrysanthemum* spp.
Dandelion‡	*Taraxacum officinale* Wiggers
Fleabane‡	*Erigeron* spp.
Goldenrod*	*Solidago* spp.
Hawkweed†	*Hieracium* spp.
Joe-pye-weed†	*Eupatorium purpureum* L.

TABLE A-1 (continued)

Common Name	Scientific Name
Composites	
Ragwort, Small's*	*Senecio smallii* Britton
Spanish needle†	*Bidens bipinnata*
White snakeroot*	*Eupatorium rugosum* Houtt.
Wild lettuce‡	*Lactuca scariola* L.
Trees and Shrubs	
Alder, European black†	*Alnus glutinosa* (L.) Gaertn.
Autumn-olive*	*Elaeagnus umbellata* Thunb.
Blackgum†	*Nyssa sylvatica* Marsh
Cherry, black†	*Prunus serotina* Ehrh.
Filbert‡	*Corylus* spp. L.
Locust, black*	*Robinia pseudoacacia* L.
Maple, red*	*Acer rubrum* L.
Oak, sawtooth‡	*Quercus acutissima* Carrathers
Pine, loblolly*	*Pinus taeda* L.
Pine, shortleaf*	*Pinus echinata* Mill.
Pine, Virginia*	*Pinus virginiana* Mill.
Shrub lespedeza*	*Lespedeza bicolor* Turcz.
Sourwood*	*Oxydendrum arboreum* (L.) DC.
Sumac*	*Rhus* spp. L.
Sweetgum*	*Liquidambar styraciflua* L.
Yellow-poplar*	*Liriodendron tulipifera* L.
Willow, black†	*Salix nigra* Marsh.
Miscellaneous	
Blackberry*	*Rubus allegheniensis* Porter
Blueberry†	*Vaccinium vacillans* Soland.
Buckwheat: Knotweed‡	*Polygonum* spp.
Smartweed, Pennsylvania*	*Polygonum pennsylvanicum* L.
Sorrell, red‡	*Rumex acetosella* L.
Cattails*	*Typha latifolia* L.
Cinquefoil†	*Potentilla canadensis* L.
Ferns and allies:	
Club moss‡	*Lycopodium* spp.
Fern, bracken‡	*Pteridium aquilinum* (L.) Kuhn.
Fern, Hartford‡	*Lygodium palmatum* (Bernh.) Swartz
Fireweed‡	*Epilobium angustifolium* L.
Fungi: Puffball‡	*Calvatia* spp.
Mushroom‡	*Amanita* spp.
Gerardia, slender†	*Gerardia tenuifolia* Vahl.
Greenbrier*	*Smilax rotundifolia* L.
Honeysuckle†	*Lonicera canadensis* Marsh.

TABLE A-1 (continued)

Common Name	Scientific Name
Miscellaneous	
Lichen, fructicose‡	*Cladonia* spp.
Loosestrife, whorled‡	*Lysimachia quadrifolia* L.
Mint†	*Mentha* spp.
Moss‡	*Polytrichum* spp. Roth
Pokeberry‡	*Phytolacca americana* L.
Purslane, common‡	*Portulaca oleracea* L.
Sedges: Nutsedge*	*Carex* spp.
Bulrush*	*Scirpus* spp.
Violet†	*Viola* spp.

* Species occurred 1975-1980.

† Not found in baseline (1975) survey, present in 1980.

‡ Absent in 1980, occurred in baseline (1975) survey.

TABLE A-2. GRASSES: OCCURRENCE AND COMPOSITION BY MINE SECTORS

	Sector 1				Sector 2				Sector 3				Sector 4			
	Occurrence*		Composition†		Occurrence		Composition		Occurrence		Composition		Occurrence		Composition	
	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980
	Percent															
Barnyard grass	-	-	-	-	-	2	-	‡	1	2	2	1	-	5	-	1
Broomsedge	12	8	3	2	7	14	3	2	13	61	12	20	6	29	3	7
Crabgrass	-	-	-	-	-	-	-	-	-	2	-	‡	-	-	-	-
Fescue, K-31	82	88	75	46	4	75	28	19	15	50	34	15	46	58	81	25
Lovegrass, weeping	7	5	3	1	4	36	41	10	5	35	6	13	-	13	-	6
Millet, foxtail	-	2	-	‡	1	-	‡	-	-	-	-	-	-	-	-	-
Oatgrass, poverty	-	-	-	-	-	5	-	1	-	11	-	3	-	11	-	2
Orchard grass	-	10	-	2	-	24	-	4	-	4	-	‡	-	8	-	1
Panic grass	4	-	1	-	8	4	1	1	14	7	17	1	5	18	7	5
Redtop grass	-	-	-	-	-	2	-	1	-	-	-	-	-	-	-	-
Ryegrass, perennial	1	-	‡	-	-	-	-	-	-	-	-	-	-	-	-	-
Switchgrass	1	-	1	-	2	2	2	‡	1	11	1	3	1	3	‡	‡

* The number of plots on which a species occurred divided by the total number sampled in the sector.

† Amount of ground cover provided by a single species related to total amount of ground cover in the sector.

‡ Less than 0.6 percent.

TABLE A-3 LEGUMES: OCCURRENCE AND COMPOSITION BY MINE SECTOR

	Sector 1				Sector 2				Sector 3				Sector 4			
	Occurrence*		Composition†		Occurrence		Composition		Occurrence		Composition		Occurrence		Composition	
	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980
	Percent															
Beggar-lice	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	1
Bushclover	-	-	-	-	-	4	-	1	-	-	-	-	-	11	-	1
Clover, red	-	-	-	-	2	-	‡	-	-	-	-	-	-	-	-	-
Lespedeza, Kobe	-	10	-	3	-	40	-	18	1	-	2	-	-	3	-	1
Lespedeza, Korean	3	8	1	1	5	13	3	4	-	2	-	1	-	11	-	5
Lespedeza, sericea	25	75	11	33	34	71	7	28	5	67	1	29	-	50	-	21
Partridge-pea	-	-	-	-	-	-	-	-	-	2	-	‡	-	8	-	1
Sweetclover, yellow	-	2	-	‡	-	4	-	‡	-	-	-	-	-	-	-	-
Sicklepod	-	-	-	-	-	-	-	-	-	-	-	-	1	-	‡	-

* The number of plots on which a species occurred divided by the total number sampled in the sector.

† Amount of ground cover provided by a single species related to total amount of ground cover in the sector.

‡ Less than 0.6 percent.

TABLE A-4. COMPOSITES: OCCURRENCE AND COMPOSITION BY MINE SECTOR

	Sector 1				Sector 2				Sector 3				Sector 4			
	Occurrence*		Composition†		Occurrence		Composition		Occurrence		Composition		Occurrence		Composition	
	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980
	--------------------------------Percent--------------------------------															
Aster species	3	28	1	2	6	16	1	2	5	15	1	1	4	50	2	9
Coreopsis	-	-	-	-	-	-	-	-	1	-	‡	-	-	5	-	1
Daisy, field	1	-	‡	-	2	-	1	-	-	-	-	-	-	-	-	-
Dandelion	-	-	-	-	-	-	-	-	-	-	-	-	2	-	1	-
Fleabane	-	-	-	-	1	-	*	-	-	-	-	-	1	-	‡	-
Goldenrod	1	25	‡	4	1	22	‡	3	-	-	-	-	-	18	-	3
Hawkweed	-	2	-	‡	-	2	-	‡	-	-	-	-	-	5	-	1
Joe-pye-weed	-	2	-	‡	-	-	-	-	-	-	-	-	-	3	-	‡
Small's ragwort	-	-	-	-	-	4	-	‡	1	-	‡	-	-	-	-	-
Spanish needle	-	-	-	-	-	-	-	-	-	4	-	2	-	3	-	‡
White snakeroot	-	2	-	‡	-	-	-	-	1	-	‡	-	-	11	-	2
Wild lettuce	1	-	‡	-	-	-	-	-	-	-	-	-	1	-	‡	-

* The number of plots on which a species occurred divided by the total number sampled in the sector.

† Amount of ground cover provided by a single species related to total amount of ground cover in the sector.

‡ Less than 0.6 percent.

TABLE A-5. MISCELLANEOUS SPECIES: OCCURRENCE AND COMPOSITION BY MINE SECTOR

	Sector 1				Sector 2				Sector 3				Sector 4			
	Occurrence*		Composition†		Occurrence		Composition		Occurrence		Composition		Occurrence		Composition	
	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980
	Percent															
Blackberry	1	18	‡	4	5	9	2	1	1	7	1	2	-	8	-	3
Blueberry	-	-	-	-	-	2	-	‡	-	-	-	-	-	3	-	1
Buckwheat:																
Knotweed	-	-	-	-	-	-	-	-	1	-	3	-	-	-	-	-
Smartweed	1	-	1	-	1	2	1	‡	2	-	5	-	2	3	1	‡
Sorrell, red	-	-	-	-	2	-	1	-	2	-	‡	-	1	-	‡	-
Cattails	2	-	1	-	3	-	4	-	1	-	2	-	1	5	1	1
Cinquefoil	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	1
Ferns and allies	-	-	-	-	-	-	-	-	4	-	1	-	-	-	-	-
Fireweed	-	-	-	-	1	-	‡	-	4	-	4	-	-	-	-	-
Fungi:																
Puffball	1	-	‡	-	-	-	-	-	-	-	-	-	-	-	-	-
Mushrooms	-	-	-	-	1	-	‡	-	1	-	‡	-	1	-	‡	-
Greenbrier	2	-	‡	-	3	4	‡	‡	6	-	2	-	-	3	-	1
Honeysuckle	-	2	-	1	-	-	-	-	-	-	-	-	-	-	-	-

TABLE A-5 (continued)

	Sector 1				Sector 2				Sector 3				Sector 4			
	Occurrence*		Composition†		Occurrence		Composition		Occurrence		Composition		Occurrence		Composition	
	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980
	Percent															
Lichen, fructicose	1	-	‡	-	1	-	‡	-	1	-	‡	-	-	-	-	-
Loosestrife, whorled	-	-	-	-	-	-	-	-	1	-	‡	-	-	-	-	-
Mint	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	‡
Moss	4	-	‡	-	2	-	1	-	4	-	4	-	5	-	‡	-
Pokeberry	1	-	‡	-	1	-	‡	-	-	-	-	-	2	-	2	-
Purslane, common	-	-	-	-	-	-	-	-	1	-	‡	-	-	-	-	-
Sedges:																
Nutsedge	1	-	‡	-	4	7	1	2	1	15	‡	9	2	16	1	4
Bulrush	2	-	2	-	3	2	1	1	1	2	2	‡	1	-	1	-
Slender gerardia	-	-	-	-	-	-	-	-	-	2	-	‡	-	-	-	-
Violet	-	-	-	-	-	-	-	-	-	2	-	‡	-	5	-	‡

* The number of plots on which a species occurred divided by the total number sampled in the sector.

† Amount of ground cover provided by a single species related to total amount of ground cover in the sector.

‡ Less than 0.6 percent.

APPENDIX B

(Supplemental Information on Birds and Small Mammals)

TABLE B-1. COMMON AND SCIENTIFIC NAMES OF BIRDS AND MAMMALS

Common name	Scientific name
Birds	
Mallard	*Anas platyrhynchos*
Red-tailed hawk	*Buteo jamaicensis*
Mourning dove	*Zenaida macroura*
Yellow-billed cuckoo	*Coccyzus americanus*
Ruby-throated hummingbird	*Archilochus colubris*
Pileated woodpecker	*Dryocopus pileatus*
Red-bellied woodpecker	*Melanerpes carolinus*
Downy woodpecker	*Picoides pubescens*
E. phoebe	*Sayornis phoebe*
Blue jay	*Cyanocitta cristata*
Common crow	*Corvus brachyrhynchos*
Carolina chickadee	*Parus carolinensis*
Tufted titmouse	*Parus bicolor*
White-breasted nuthatch	*Sitta carolinensis*
Red-breasted nuthatch	*Sitta canadensis*
Winter wren	*Troglodytes troglodytes*
Carolina wren	*Thryothorus ludovicianus*
Gray catbird	*Dumatella carolinensis*
Brown thrasher	*Toxostoma rufum*
Am. robin	*Turdus migratorius*
Hermit thrush	*Hylocichla guttata*
E. bluebird	*Sialia sialis*
Golden-crowned kinglet	*Regulus satrapa*
Red-eyed vireo	*Vireo olivaceus*
Black-and-white warbler	*Mniotilta varia*
Golden-winged warbler	*Vermivora chrysoptera*
Myrtle warbler	*Dendroica coronata*
Prairie warbler	*Dendroica discolor*
Ovenbird	*Seiurus aurocapillus*
Common yellowthroat	*Geothlypis trichas*
Yellow-breasted chat	*Icteria virens*
Red-winged blackbird	*Agelaius phoeniceus*
Cardinal	*Cardinalis cardinalis*
Indigo bunting	*Passerina cyanea*

TABLE B-1 (continued)

Common name	Scientific name
Birds	
Am. goldfinch	*Carduelis tristis*
Rufous-sided towhee	*Pipilo erythrophthalmus*
Slate-colored junco	*Junco hyemalis*
Tree sparrow	*Spizella arborea*
Chipping sparrow	*Spizella passerina*
Field sparrow	*Spizella pusilla*
White-throated sparrow	*Zonotrichia leucophrys*
Fox sparrow	*Passerella iliaca*
Song sparrow	*Melospiza melodia*
Mammals	
Smoky shrew	*Sorex fumeus*
Long-nosed shrew	*Sorex longirostris*
Southeastern shrew	*Cryptotis parva*
Short-tailed shrew	*Blarina brevicauda*
E. chipmunk	*Tamias striatus*
E. harvest mouse	*Reithrodontomys humilis*
Deer mouse	*Peromyscus maniculatus*
White-footed mouse	*Peromyscus leucopus*
Golden mouse	*Ochrotomys nuttalli*
E. wood rat	*Neotoma floridana*
Hispid cotton rat	*Sigmodon hispidus*
S. bog lemming	*Synaptomys cooperii*
Meadow vole	*Microtus pennsylvanicus*
House mouse	*Mus musculus*
E. cottontail	*Sylvilagus floridanus*
Red fox	*Urocyon cinereoargentatus*
Gray fox	*Vulpes fulva*

TABLE B-2. BREEDING BIRD POPULATION OF SECTOR 1, MEAN NUMBER PER PLOT

Species	1976	1977	1978	1979	1980	5-year mean	Correlation coefficient
Ruby-throated hummingbird	-	-	-	0.033	-	0.007	0.082
E. phoebe	0.067	-	-	-	-	.013	-.164
Gray catbird	-	0.053	-	-	0.033	.017	.018
Brown thrasher	-	-	-	-	.033	.007	
Red-eyed vireo	-	.033	-	-	.053	.017	.096
Black-and-white warbler	-	-	-	-	.053	.011	.164
Golden-winged warbler	-	.240	0.067	.033	.167	.101	.057
Prairie warbler	.087	.053	.053	.193	.100	.097	.092
Common yellowthroat	-	-	-	.067	-	.013	.082
Yellow-breasted chat	-	-	.033	-	.067	.020	.193*
Red-winged blackbird	.273	.100	.473	.067	.183	.219	-.052
Cardinal	-	-	-	-	.033	.007	.176
Indigo bunting	.640	.407	.447	.600	.580	.535	.035
Am. goldfinch	.140	-	.033	-	-	.035	-.264*
Rufous-sided towhee	-	-	.167	.033	.153	.071	.181
Field sparrow	.827	.067	.153	.287	.513	.367	-.109
Song sparrow	.033	.067	.033	-	.187	.064	.130
TOTAL	2.067	1.020	1.493	1.413	2.160	1.631	.078
NOSPP	2.200	1.067	1.400	1.667	2.533	1.773	.161

* Significant ($p < 0.05$) correlation with year.

TABLE B-3. BREEDING BIRD POPULATION OF SECTOR 2, MEAN NUMBER PER PLOT

Species	1976	1977	1978	1979	1980	5-year mean	Correlation coefficient
Yellow-billed cuckoo	0.036	-	-	-	-	0.007	-0.170
Carolina chickadee	-	-	-	-	0.071	.014	.170
Tufted titmouse	.143	-	-	-	-	.029	-.348*
Red-eyed vireo	-	-	0.071	-	.036	.021	.077
Golden-winged warbler	-	-	-	-	.114	.023	.243*
Prairie warbler	.236	-	-	0.036	-	.054	-.331*
Ovenbird	.057	-	-	-	-	.011	-.170
Red-winged blackbird	.093	-	.164	.164	.143	.113	.088
Indigo bunting	.607	0.057	.271	.750	.664	.470	.240*
Am. goldfinch	.036	-	-	-	.107	.029	.108
Rufous-sided towhee	.057	-	.036	.036	.107	.047	.107
Field sparrow	.271	.257	.300	.636	.850	.463	.361*
TOTAL	1.499	.314	.843	1.621	2.092	1.274	.320*
NOSPP	2.071	.286	1.000	1.643	2.000	1.400	.153

* Significant ($p < 0.05$) correlation with year.

TABLE B-4. BREEDING BIRD POPULATION OF SECTOR 3, MEAN NUMBER PER PLOT

Species	1976	1977	1978	1979	1980	5-year mean	Correlation coefficient
Golden-winged warbler	-	-	-	-	0.077	0.015	0.252*
Prairie warbler	-	-	0.177	0.200	.415	.158	.452*
Yellow-breasted chat	0.039	-	-	-	-	.008	-.177
Red-winged blackbird	.139	-	.039	-	.154	.066	.013
Indigo bunting	.577	-	.239	.369	.315	.300	-.055
Am. goldfinch	.077	-	-	.077	-	.031	-.063
Rufous-sided towhee	-	-	-	-	.115	.023	.239*
Field sparrow	.215	0.177	.315	.769	.792	.454	.419*
Song sparrow	-	-	-	-	.038	.008	.177
TOTAL	1.046	.177	.762	1.415	1.908	1.062	.389*
NOSPP	1.308	.231	.846	1.540	2.132	1.211	.376*

* Significant ($p < 0.05$) correlation with year.

TABLE B-5. BREEDING BIRD POPULATION OF SECTOR 4, MEAN NUMBER PER PLOT

Species	1976	1977	1978	1979	1980	5-year mean	Correlation coefficient
Prairie warbler	0.045	-	-	-	0.091	0.027	0.087
Yellow-breasted chat	-	-	-	-	.091	.018	.193
Red-winged blackbird	.254	0.482	1.127	1.254	.855	.794	.184
Indigo bunting	.236	-	.164	-	.309	.142	.070
Am. goldfinch	.091	-	-	-	-	.018	-.193
Rufous-sided towhee	-	-	-	-	.091	.018	.193
Chipping sparrow	-	-	-	.045	-	.009	.096
Field sparrow	.236	-	-	.236	.445	.184	.266*
Song sparrow	-	-	-	.045	.182	.045	.294*
TOTAL	.864	.482	1.291	1.582	2.182	1.280	.300*
NOSPP	1.182	.273	.454	1.000	1.723	.927	.265*

* Significant ($p < 0.05$) correlation with year.

TABLE B-6. CORRELATION COEFFICIENTS (r) OR VEGETATION VARIABLES WITH YEAR

	Sectors				All sectors combined
	1	2	3	4	
TOTCOV	.492*	.521*	.051	.487*	.340*
NATCOV	.179	.076	.726*	-.003	.254*
REVCOV	-.203	.185	-.528*	.369*	-.070
HERBDIV	.266	.377*	.105	.558*	.321*
HERBHT	.849*	.781*	.801*	.870*	.811*
HERBHC	.698*	.744*	.688*	.792*	.700*
GRAMCOV	-.283*	-.603*	-.281*	-.315*	-.346*
FORBCOV	.261	.845*	.495*	.763*	.580*
TOTWOOD	-.116	.312*	.426*	-.030	.144*
WOODA	.143	.278*	.200	.178	.197*
WOODB	-.096	.201	.196	-.133	.001
WOODC	.003	.170	.184	.062	.066
WOODD	-.046	†	.094	.275*	.040

* Significant correlation, $p < 0.05$.

† No value.

TABLE B-7. CORRELATION COEFFICIENTS (r) OF VEGETATION VARIABLES WITH BREEDING BIRD POPULATION PARAMETERS

	TOTCOV	NATCOV	REVCOV	HERBHT	HERBHC	HERBDIV	GRAMCOV	FORBCOV	TOTWOOD	WOODA	WOODB	WOODC	WOODD
TOTAL	.279*	.018	.058	.249*	.308*	.080	-.071	.164*	.114	-.006	.013	.407*	.114
NOSPP	.292*	.022	.049	.234*	.303*	.064	-.083	.141*	.014	-.016	-.011	.156*	.044
Tufted titmouse	-.034	-.126*	.029	-.115	-.104	-.103	-.008	-.084	-.007	-.032	-.038	-.024	-.026
Golden-winged warbler	.182*	.049	.003	.005	.128*	.097	.068	-.017	.118	-.057	.156*	.074	.096
Prairie warbler	-.001	.129*	-.114	.124	.054	.037	.016	-.016	.049	-.026	-.038	-.066	.141*
Yellow-breasted chat	.177*	.010	.014	.123	.202*	.065	.005	.020	.045	-.026	-.031	.079	.158*
Red-winged blackbird	.097	.039	.021	.108	.107	.049	-.004	.060	.198*	.032	.072	.537*	.052
Indigo bunting	.196*	-.095	.139*	.031	.148*	.004	.009	.047	-.058	-.009	-.030	-.035	-.020
Am. goldfinch	-.019	-.036	-.001	.059	.041	-.070	-.064	.050	-.046	-.050	-.047	.072	.061
Rufous-sided towhee	.183*	-.029	.062	.132*	.195*	.021	.004	.010	-.027	.034	-.063	.039	.029
Field sparrow	.101	.006	-.017	.204*	.178*	.030	-.182*	.230*	-.040	.024	-.063	.008	.041
Song sparrow	.060	.029	.006	.051	.077	.095	.050	.002	-.021	.017	.038	.034	-.030

*Significant correlation, $p < 0.05$.

TABLE B-8. CORRELATION COEFFIEIENTS (r) OF VEGETATION VARIABLES WITH TOTAL AND NOSPP BY SECTOR

Vegetation variable	TOTAL				NOSPP			
	1	2	3	4	1	2	3	4
TOTCOV	-.114	.446*	.229	.334*	.058	.430*	.254*	.184
NATCOV	.200	.032	.083	-.055	.233	.038	.114	-.059
REVCOV	-.212	.123	.029	.005	-.237	.148	.035	-.006
HERBHT	-.144	.262*	.357*	.348*	.003	.139	.396*	.327*
HERBHC	-.106	.347*	.338*	.356*	.033	.249*	.398*	.350*
HERBDIV	.081	.069	.126	.146	.122	.005	.099	.130
GRAMCOV	.047	-.170	-.157	-.244	.017	-.134	-.127	-.299*
FORBCOV	-.040	.235*	.350*	.192	-.013	.151	.334*	.179
TOTWOOD	-.064	.054	.146	.220	-.117	.043	.134	.172
WOODA	-.111	.158	-.079	-.090	-.084	.110	-.136	.063
WOODB	.020	-.018	.200	.110	-.089	.045	.322*	.019
WOODC	.161	.078	.264*	.439*	.282*	.083	.320*	.250
WOODD	-.031	†	.037	.314*	-.123	†	†	.320*

* Significant correlation, $p < 0.05$.

† No value.

TABLE B-9. DETERMINATION OF VEGETATION VARIABLES AS PREDICTORS OF TOTAL AND NOSPP

The "best" prediction equation for TOTAL with all sectors combined is:

$$TOTAL = 0.758 + 0.0094\ HERBHC + 1.8011\ WOODC + 0.5727\ WOODD$$

The coefficient at determination (R^2), or the proportion of the variance in TOTAL explained by the equation is 0.2549. For NOSPP, the prediction equation for all sectors combined is:

$$NOSPP = 0.6154 + 0.0080\ TOTCOV + 0.0057\ HERBHC + 0.4929\ WOODC;\ R^2 = 0.1204$$

Similar multiple regression analyses were also performed for each of the sectors.

For Sector 1:

$$TOTAL = 2.1714 - 0.0221\ REVCOV + 0.0145\ GRAMCOV;\ R^2 = 0.1029$$

$$NOSPP = 1.4564 + 0.0172\ NATCOV - 0.2691\ TOTWOOD + 0.9762\ WOODC;\ R^2 = 0.1750$$

For Sector 2:

$$TOTAL = 0.0036 + 0.0321\ TOTCOV - 1.5135\ HERBDIV;\ R^2 = 0.2324$$

$$NOSPP = 1.1271 + 0.0448\ TOTCOV - 1.5960\ HERBDIV - 0.0182\ GRAMCOV - 0.0223\ FORBCOV;\ R^2 = 0.2994$$

For Sector 3:

$$TOTAL = 0.3303 + 0.0054\ HERBHT + 0.0148\ FORBCOV - 0.0937\ WOODA + 1.8227\ WOODC;\ R^2 = 0.2791$$

$$NOSPP = 0.6443 - 0.0119\ NATCOV + 0.0104\ HERBHT + 0.0122\ FORBCOV - 0.1268\ WOODA + 2.3704\ WOODC;\ R^2 = 0.3900$$

For Sector 4:

$$TOTAL = 0.3911 + 0.0051\ HERBHT + 0.2252\ WOODB + 2.9601\ WOODC + 4.9095\ WOODD;\ R^2 = 0.7909$$

$$NOSPP = 1.7311 - 0.0136\ NATCOV - 0.0155\ REVCOV + 0.0103\ HERBHC + 2.0457\ WOODD;\ R^2 = 0.4050$$

TABLE B-10. WINTER BIRD POPULATION OF SECTOR 1, MEAN NUMBER PER PLOT

Species	1977	1978	1979	1980	1981	5-year mean
Red-bellied woodpecker	-	-	-	-	0.019	0.004
Downy woodpecker	-	-	-	-	.019	.004
Blue jay	-	0.017	0.033	-	-	.010
Carolina chickadee	-	-	.100	-	.154	.051*
Winter wren	-	-	.017	-	.038	.011
Carolina wren	-	-	-	0.017	-	.003
Am. robin	-	-	-	-	.019	.004
Hermit thrush	-	-	-	.033	.154	.037*
E. bluebird	-	-	-	.017	-	.003
Golden-crowned kinglet	-	-	-	.067	.096	.033*
Myrtle warbler	-	-	-	.033	-	.007
Cardinal	0.250	.130	.017	.200	.192	.158
Am. goldfinch	-	-	-	.017	-	.003
Rufous-sided towhee	-	-	-	.017	.038	.011
Slate-colored junco	.730	.333	.483	1.233	.750	.706
Field sparrow	-	.050	.083	.300	-	.087
White-throated sparrow	.083	-	.117	.450	.135	.157
Fox sparrow	-	-	-	-	.019	.004
Song sparrow	-	.070	.017	.350	.865	.260*
Unidentified sparrow	.070	-	-	-	-	.014
WTOTAL	1.133	.600	.867	2.701	2.498	1.560*
WNOSPP	1.000	1.000	1.000	3.133	2.733	1.773*

* Significant correlation with year, $p < 0.05$.

TABLE B-11. WINTER BIRD POPULATION OF SECTOR 2, MEAN NUMBER PER PLOT

Species	1977	1978	1979	1980	1981	5-year mean
Mourning dove	-	-	0.018	-	-	0.004
Pileated woodpecker	-	-	-	-	0.018	.004
Downy woodpecker	-	-	-	0.018	.018	.007
Common crow	0.036	-	-	-	-	.007
Blue jay	.036	-	-	-	.018	.011
Carolina chickadee	-	-	.054	.107	.161	.064*
Tufted titmouse	-	-	.054	.036	.018	.022
Winter wren	-	-	-	-	.054	.011*
Carolina wren	-	-	-	.036	.018	.011
Am. robin	-	-	-	.018	-	.004
Hermit thrush	-	-	-	.018	-	.004
Golden-crowned kinglet	-	-	.018	-	.089	.021*
Red-winged blackbird	-	-	.018	-	-	.004
Cardinal	-	0.018	-	.018	.125	.032*
Slate-colored junco	.410	.410	1.80	.804	.821	.849
Field sparrow	-	-	.036	.018	.018	.014
White-throated sparrow	.018	-	-	.018	-	.007
Song sparrow	-	.018	.143	.179	.071	.082*
Unidentified sparrow	.018	-	-	-	-	.004*
WTOTAL	.518	.446	2.141	1.270	1.429	1.161
WNOSPP	.857	.642	1.214	2.000	3.071	1.557*

* Significant correlation with year, $p < 0.05$.

TABLE B-12. WINTER BIRD POPULATION OF SECTOR 3, MEAN NUMBER PER PLOT

Species	1977	1978	1979	1980	1981	5-year mean
Downy woodpecker	-	-	-	-	0.019	0.004
Carolina chickadee	-	-	-	0.154	.231	.077*
Tufted titmouse	-	-	-	.038	.019	.011
White-breasted nuthatch	-	-	-	-	.019	.004
Red-breasted nuthatch	-	-	-	-	.038	.008
Winter wren	-	-	-	-	.058	.012
Carolina wren	-	-	-	-	.019	.004
Brown thrasher	-	-	-	.019	-	.004
Hermit thrush	-	-	-	-	.019	.004
E. bluebird	-	-	-	.058	-	.012
Golden-crowned kinglet	-	-	-	.058	.635	.139*
Cardinal	-	0.019	0.019	-	.019	.011
Am. goldfinch	-	-	-	.019	-	.004
Rufous-sided towhee	-	-	-	-	.019	.004
Slate-colored junco	0.960	-	.173	.558	.096	.357
Field sparrow	-	-	.462	.558	.269	.258*
Tree sparrow	-	.269	-	-	-	.054
White-throated sparrow	-	-	-	.077	.038	.023
Song sparrow	.058	.019	-	.038	.038	.031
Unidentified sparrow	.077	-	-	-	.019	.019
WTOTAL	1.095	.307	.654	1.577	1.555	1.038
WNOSPP	.462	.231	1.000	2.077	2.538	1.262*

* Significant correlation with year, $p < 0.05$.

TABLE B-13. WINTER BIRD POPULATION OF SECTOR 4, MEAN NUMBER PER PLOT

Species	1977	1978	1979	1980	1981	5-year mean
Mallard	-	-	-	0.045	-	0.009
Red-tailed hawk	0.023	-	-	-	-	.005
Downy woodpecker	-	-	-	-	0.045	.009
Common crow	.068	-	-	-	-	.014*
Carolina chickadee	-	-	-	-	.341	.068*
Winter wren	-	-	-	.023	.114	.027*
Golden-crowned kinglet	-	-	-	-	.409	.082*
Cardinal	-	-	-	-	.341	.068*
Am. goldfinch	-	-	0.114	-	-	.023
Slate-colored junco	.090	0.159	.045	.386	1.159	1.839*
Field sparrow	-	.023	.068	.023	.045	.032
Tree sparrow	-	.023	.159	-	-	.036
White-throated sparrow	.045	-	-	-	-	.009
Song sparrow	-	.045	.295	.409	.318	.213*
Unidentified sparrow	.023	-	-	-	-	.005
WTOTAL	.249	.250	.681	.886	2.772	.968*
WNCSPP	.545	.909	.818	1.273	3.637	1.436*

* Significant correlation with year, $p < 0.05$.

TABLE B-14. CORRELATION COEFFICIENTS (r) OF VEGETATION VARIABLES WITH WINTER BIRD POPULATION PARAMETERS

	TOTCOV	NATCOV	REVCOV	HERBHT	HERBHC	HERBDIV	GRAMCOV	FORBCOV	TOTWOOD	WOODA	WOODB	WOODC	WOODD
WTOTAL	.187*	.154*	-.097	.249*	.270*	.243*	-.221*	.263*	.104	.108	.025	.024	-.006
WNOSPP	.258*	.199*	-.122	.432*	.429*	.284*	-.275*	.379*	.114	.062	.083	.031	.038
Carolina chickadee	.094	.188*	-.121	.325*	.270*	.209*	-.133*	.210*	.140*	.102	.071	-.040	.095
Winter wren	.093	.039	.008	.149*	.123	.172*	-.180*	.223*	.007	-.011	.066	-.038	-.040
Hermit thrush	.176*	.103	-.059	.169*	.218*	.197*	-.126	.160*	.029	.034	.031	-.029	-.031
Golden-crowned kinglet	.025	.338*	-.243	.307*	.208*	.131*	-.011	.074	-.022	-.027	.020	-.016	-.022
Cardinal	.172*	.060	.043	.089	.189*	.123	.058	.034	.019	-.025	-.014	-.037	.204*
Slate-colored junco	.102	-.016	.010	.077	.115*	.161*	-.226*	.188*	.111	.141*	.037	-.037	-.050
Field sparrow	-.096	.170*	-.208*	.152*	.037	-.012	-.077	.104	-.087	-.102	-.043	.040	.115*
White-throated sparrow	.196*	.021	.019	.123	.229*	.096	-.006	.034	.105	.125	-.005	.065	-.037
Song sparrow	.291*	.156*	-.072*	.211*	.295*	.206*	-.150*	.223*	.013	-.003	-.035	.166*	-.019

* Significant correlation, $p < 0.05$.

TABLE B-15. CORRELATION COEFFICIENTS (r) OF VEGETATION VARIABLES WITH WTOTAL AND WNOSPP BY SECTOR

Vegetation variable	WTOTAL				WNOSPP			
	1	2	3	4	1	2	3	4
TOTCOV	.143	.204	-.074	.406*	.143	.394*	.046	.413*
NATCOV	.374*	.157	.122	.161	.440*	.082	.315*	.086
REVCOV	-.287*	-.063	-.172	-.018	-.387*	-.066	-.255*	.122
HERBHT	.295*	.070	.248	.507*	.375*	.326*	.512*	.558*
HERBHC	.223	.101	.201	.601*	.282*	.373*	.468*	.610*
HERBDIV	.335*	.284*	-.223	.496*	.414*	.249*	-.031	.480*
GRAMCOV	-.347*	-.330*	-.176	-.122	-.440*	-.414*	-.233	.160
FORBCOV	.358*	.324*	.124	.270*	.452*	.436*	.311*	.409*
TOTWOOD	.034	.368*	-.061	.036	-.016	.394*	.030	.038
WOODA	.297*	.389*	-.202	-.059	.121	.266*	-.056	-.035
WOODB	-.089	.122	.332*	-.029	-.064	.417*	.259*	-.058
WOODC	-.101	-.048	-.068	.224	-.035	-.036	-.025	.130
WOODD	-.139	†	.077	.232	-.085	†	-.013	.466*

* Significant correlation, $p < 0.05$.

† No value.

TABLE B-16. DETERMINATION OF VEGETATIVE VARIABLES AS PREDICTORS OF WTOTAL AND WNOSPP

The "best" prediction equation for WTOTAL with all sectors combined is:

WTOTAL = 0.8764 + 0.0097 NATCOV + 0.0101 HERBHC + 0.1123 HERBDIV
- 0.0143 GRAMCOV; $R^2 = 0.1374$

For WNOSPP, all sectors combined:

WNOSPP = 0.8212 + 0.0063 HERBHT + 0.0079 HERBHC + 0.1378 HERBDIV
- 0.0121 GRAMCOV; $R^2 = 0.2528$

Similar multiple regression analyses were also performed for each of the sectors.

For Sector 1:

WTOTAL = -0.5603 + 0.0426 NATCOV + 0.0140 HERBHT + 0.7759 WOODA;
$R^2 = 0.2759$

WNOSPP = -0.1753 + 0.0457 NATCOV + 0.0147 HERBHT; $R^2 = 0.3317$

For Sector 2:

WTOTAL = 1.9661 - 0.0321 GRAMCOV + 0.7878 WOODA; $R^2 = 0.2402$

WNOSPP = 1.2162 + 0.0285 TOTCOV - 0.2769 HERBDIV - 0.0225 GRAMCOV
+ 0.4338 WOODA + 1.3912 WOODB; $R^2 = 0.4347$

For Sector 3:

WTOTAL = 1.8755 - 0.4445 HERBDIV + 0.0211 FORBCOV + 1.7569 WOODB;
$R^2 = 0.2417$

WNOSPP = 0.3676 + 0.0170 HERBHT - 0.4550 WOODA; $R^2 = 0.3299$

For Sector 4:

WTOTAL = 0.0387 - 0.0192 TOTCOV + 0.0368 HERBHC + 0.5185 HERBDIV
- 0.0400 FORBCOV; $R^2 = 0.5531$

WNOSPP = 0.2042 + 0.0156 HERBHC + 0.2492 HERBDIV + 2.4604;
$R^2 = 0.5145$

TABLE B-17. SPECIES DIVERSITY (H´) OF SMALL MAMMALS TRAPPED ON THE OLLIS CREEK STRIP MINE

Sector		1976	1977	1978	1979	1980
1	Summer	1.001	0.477	0.907	0.723	0.177
	Fall	1.782	.669	1.731	1.164	.648
	Combined	1.842	1.282	1.532	1.747	1.408
2	Summer	.590	.177	.485	0	0
	Fall	.711	-*	1.000	.500	0
	Combined	1.059	.250	.868	.863	.940
3	Summer	.272	0	.129	.272	0
	Fall	.042	1.164	.470	.461	0
	Combined	.149	1.146	.397	.524	0
4	Summer	0	0	.235	0	0
	Fall	†	0	0	.500	0
	Combined	0	0	.267	1.371	0

* No captures.

† Not trapped.

APPENDIX C

(Supplemental information on water quality)

TABLE C-1. THE MEAN AND RANGE OF SELECTED WATER QUALITY PARAMETERS FOUND IN NO BUSINESS CREEK FROM JANUARY 1976 THROUGH JULY 1980

		Station 1 NBCM 0.03	Station 2 NBCM 0.20	Station 3 NBCM 0.49
Water temp. C	Mean	11.5	12.1	12.0
	Range	0.6-19.4	0.6-18.9	0.6-18.9
pH	Mean	6.2	6.1	6.1
	Range	5.2-8.4	5.3-8.4	5.2-8.4
Total acidity mg/l	Mean	4.0	5.0	5.4
	Range	K-38*	K-42	K-47
Iron mg/l	Mean	0.23	0.11	0.20
	Range	0.05-2.6	0.07-1.50	0.09-4.10
Manganese mg/l	Mean	0.06	0.26	0.03
	Range	0.01-0.40	0.01-1.40	0.01-0.60
Sulfate mg/l	Mean	6.1	5.7	6.0
	Range	2-13	1-12	1-12
Turbidity JTU	Mean	1.5	1.1	2.0
	Range	K-9	K-4	K-14

* K indicates value less than 1.0.

TABLE C-2. COMPARISON OF WATER QUALITY PARAMETERS COLLECTED QUARTERLY AT THOMPSON CREEK MILE 0.01 (STATION 8) DURING MINING AND CONVENTIONAL RECLAMATION, DURING REMEDIAL TREATMENT, AND POST RECLAMATION PERIODS

Date	Water temp. C	Turbidity JTU	pH	Total alkalinity $CaCO_3$ mg/1	Total acidity $CaCO_3$ mg/1	Sulfate mg/1	Iron mg/1	Manganese mg/1	Total hardness mg/1
During mining and conventional reclamation									
02-10-71	0.3	5	5.0	-	21	65	0.33	6.30	31
04-13-71	11.7	4	4.6	-	11	35	0.16	4.00	24
07-07-71	21.7	2	4.5	0	20	-	0.31	8.10	58
11-02-71	15.0	10	4.4	-	22	110	1.30	13.00	86
02-09-72	-	-	4.0	-	-	-	-	-	-
04-18-72	10.8	5	3.7	0	46	180	1.50	31.00	190
07-25-72	21.4	1	3.6	0	65	230	0.61	28.00	180
10-25-72	10.8	1	3.8	0	33	120	0.63	14.00	87
During remedial treatment*									
10-30-75	-	<1	3.8	0	120	98	0.15	1.90	-
01-21-76	1	<1	4.7	0	-	62	0.23	1.50	-
04-07-76	11.7	<1	4.5	0	-	69	0.28	1.70	-
07-14-76	19.4	<1	4.8	0	21	95	0.30	1.60	-
10-20-76	8.3	<1	4.2	0	32	140	0.42	2.70	-
Post reclamation									
04-12-77	13.3	1	4.1	0	20	110	0.19	1.40	-
07-27-77	-	1	4.2	0	15	60	0.15	1.80	-
10-27-77	13.5	1	5.0	0	6	47	0.16	0.91	-
01-04-78	0.3	5	4.6	0	27	80	0.72	2.00	-
04-05-78	15.0	2	4.7	0	20	66	0.41	2.50	-
07-20-78	22.2	2	3.8	0	32	130	0.29	2.50	-
10-12-78	16.5	<1	5.0	0	17	110	0.09	3.00	-
01-18-79	3.0	1	4.6	<1	28	96	0.32	2.00	-
04-11-79	11.0	1	4.1	0	20	46	0.39	0.83	-
07-31-79	21.0	<1	4.1	0	42	79	0.14	2.00	-
10-10-79	9.5	<1	4.4	0	<1	120	0.17	3.00	-

TABLE C-2 (continued)

Date	Water temp. C	Turbidity JTU	pH	Total alkalinity $CaCO_3$ mg/1	Total acidity $CaCO_3$ mg/1	Sulfate mg/1	Iron mg/1	Manganese mg/1	Total hardness mg/1
01-24-80	5.0	2	4.5	0	13	48	0.17	0.73	-
04-21-80	12.0	4	4.5	0	11	49	0.10	0.93	-
07-21-80	1	1	4.5	0	13	83	0.13	1.40	-

* Limited remedial treatment, fall of 1974, spring of 1975.

TABLE C-3. COMPARISON OF WATER QUALITY PARAMETERS COLLECTED QUARTERLY AT AN UNNAMED TRIBUTARY TO OLLIS CREEK (STATION 7) BEFORE REMEDIAL TREATMENT, DURING REMEDIAL TREATMENT, AND AFTER REMEDIAL TREATMENT

Date	Water temp. C	Turbidity JTU	pH	Total alkalinity $CaCO_3$ mg/1	Total acidity $CaCO_3$ mg/1	Sulfate mg/1	Iron mg/1	Manganese mg/1
Before remedial treatment								
10-30-75	14.4	6.8	3.5	0	150	600	4.00	23.00
During remedial treatment								
01-21-76	-	14.0	5.8	2	28	420	9.40	14.00
04-07-76	18.9	28.0	5.0	0	27	400	5.40	8.50
07-14-76	24.4	15.0	5.0	0	27	350	1.90	9.50
10-20-76	10.0	29.0	4.6	0	55	820	4.20	1.50
04-12-77	13.3	12.0	4.4	0	25	400	4.00	6.90
07-27-77	21.5	14.0	3.9	0	37	340	2.30	-
10-27-77	14.5	12.0	4.8	0	35	220	4.50	-
After remedial treatment								
01-04-78	3.9	7.0	5.1	0	39	320	8.50	25.00
04-05-78	15.5	23.0	5.7	5	13	75	1.90	7.40
07-20-78	22.2	5.0	4.0	0	66	680	1.40	23.00
10-12-78	13.0	8.0	5.2	1	30	570	2.10	17.00
01-18-79	6.0	25.0	5.0	4	38	400	7.80	9.70
04-11-79	17.0	17.0	4.4	0	43	310	3.80	8.30
07-31-79	23.0	5.0	3.8	0	88	460	1.30	16.00
10-10-79	11.0	6.0	4.7	0	<1	610	3.70	20.00
01-24-80	8.0	17.0	4.4	0	36	340	3.90	7.80
04-21-80	17.0	6.0	4.8	<1	11	280	2.40	15.00
07-21-80	-	7.0	4.3	0	25	530	0.57	15.00

TABLE C-4. COMPARISON OF WATER QUALITY PARAMETERS COLLECTED QUARTERLY AT LAUREL BRANCH MILE 0.1 (STATION 4) DURING A PERIOD OF LIMITED MINING AND CONVENTIONAL RECLAMATION AND AFTER CONVENTIONAL RECLAMATION

Date	Water temp. C	Turbidity JTU	pH	Total alkalinity CaCO$_3$ mg/1	Total acidity CaCO$_3$ mg/1	Sulfate mg/1	Iron mg/1	Manganese mg/1
During limited mining and conventional reclamation								
07-07-71	20.6	20	6.6	12	2	-	1.20	0.03
10-04-71	17.5	20	6.8	9	7	15	1.50	0.02
02-09-72	-	-	6.5	-	-	-	-	-
04-18-72	13.5	15	6.6	4	2	17	1.20	0.24
07-25-72	21.4	20	6.8	14	-	110	1.50	0.54
10-25-72	10.5	9	6.1	4	3	70	1.30	1.80
After conventional reclamation								
08-25-75	22.8	10	5.1	2	10	220	0.71	4.10
10-30-75	12.0	150	4.2	0	7	59	0.40	1.80
During remedial treatment								
01-21-76	-	5	5.8	2	2	42	0.56	1.20
04-07-76	10.0	7	5.4	1	7	59	0.55	1.30
07-14-76	17.8	5	6.0	2	6	10	0.73	1.80
10-20-76	8.3	3	5.5	2	10	200	0.55	4.20
04-12-77	12.2	7	4.9	0	5	81	0.44	1.40
07-27-77	21.5	3	5.5	1	6	190	0.20	4.90
10-27-77	13.5	10	4.9	2	2	38	0.61	0.82
01-04-78	0.6	6	6.0	1	4	62	0.53	2.80
04-05-78	20.0	24	4.6	0	49	170	5.00	20.00
07-20-78	25.6	10	4.9	0	7	160	0.17	2.70
10-12-78	16.0	3	6.8	4	<1	160	0.41	2.10

TABLE C-4 (continued)

Date	Water temp. C	Turbidity JTU	pH	Total alkalinity $CaCO_3$ mg/1	Total acidity CO_3 mg/1	Sulfate mg/1	Iron mg/1	Manganese mg/1
Post reclamation								
01-18-79	2.0	8	5.5	4	8	80	0.56	1.60
04-11-79	13.0	3	5.4	1	6	36	0.58	0.66
07-31-79	21.0	6	6.2	3	33	77	0.42	1.30
10-10-79	9.0	16	6.4	11	<1	120	0.93	0.95
01-24-80	5.0	3	5.7	1	5	39	0.41	0.59
04-21-80	11.0	5	6.0	4	4	44	0.09	0.62
07-21-80	22.0	9	6.4	8	4	190	0.18	0.18

TABLE C-5 COMPARISON OF WATER QUALITY PARAMETERS COLLECTED QUARTERLY AT OLLIS CREEK MILE 0.68 (STATION 1) DURING MINING AND CONVENTIONAL RECLAMATION, AFTER PARTIAL TREATMENT, DURING REMEDIAL TREATMENT, AND POST RECLAMATION PERIODS.

Date	Water temp. C	Turbidity JTU	pH	Total alkalinity $CaCO_3$ mg/1	Total acidity $CaCO_3$ mg/1	Sulfate mg/1	Iron mg/1	Manganese mg/1	Total hardness mg/1
During mining and conventional reclamation									
07-21-70	26.1	10	7.1	15	5	18	0.60	-	15
10-27-70	16.0	9	6.9	11	4	30	0.67	0.59	31
02-10-71	3.0	10	5.8	2	5	25	0.25	0.56	15
04-13-71	14.0	3	6.0	2	4	23	0.23	0.42	18
07-07-71	24.4	5	6.2	9	5	-	0.55	0.56	41
10-04-71	22.5	1	4.9	-	13	95	0.37	1.90	74
02-09-72	-	-	5.0	-	-	-	-	-	-
04-18-72	15.6	5	5.5	3	6	27	0.29	0.85	42
07-25-72	26.1	1	5.5	2	8	120	0.22	2.80	46
10-25-72	12.8	5	4.5	0	16	100	0.70	2.90	86
After limited remedial treatment									
08-25-75	21.7	2	5.4	28	32	56	0.32	0.10	-
10-30-75	14.0	<1	4.5	0	70	56	0.16	1.30	-
During remedial treatment									
01-21-76	-	3	5.4	1	7	42	0.86	0.98	-
04-07-76	11.7	2	5.2	<1	9	43	0.43	0.74	-
07-14-76	21.7	2	5.8	3	6	54	0.36	0.87	-
10-20-76	11.7	1	5.7	2	10	120	0.61	0.62	-
04-12-77	12.8	2	4.8	0	7	55	0.14	0.62	-
07-27-77	24.5	2	7.2	5	4	96	0.35	1.10	-
10-27-77	13.0	15	5.4	1	7	60	0.73	1.20	
01-04-78	1.4	4	5.1	0	14	54	0.37	1.20	-
04-05-78	14.0	1	5.5	10	12	31	0.19	1.10	-
07-20-78	25.0	2	6.5	3	13	60	0.16	0.11	-
10-12-78	11.0	<1	6.8	18	<1	41	0.15	0.02	-

TABLE C-5 (continued)

Date	Water temp. C	Turbidity JTU	pH	Total alkalinity $CaCO_3$ mg/1	Total acidity $CaCO_3$ mg/1	Sulfate mg/1	Iron mg/1	Manganese mg/1	Total hardness mg/1
Post reclamation									
01-18-79	3.0	6	5.2	2	10	50	0.32	0.82	-
04-11-79	10.0	2	4.5	0	17	44	0.22	0.86	-
07-31-79	23.5	2	5.5	2	17	57	0.24	0.68	-
10-10-79	13.5	2	6.6	4	<1	77	0.34	0.65	-
01-24-80	5.0	2	5.8	5	8	51	0.33	0.86	-
04-21-80	11.0	1	5.6	1	4	41	0.09	0.80	-
07-21-80	23.5	2	6.4	20	6	42	0.13	0.04	-

TABLE C-6. COMPARISON OF WATER QUALITY PARAMETERS COLLECTED QUARTERLY AT OLLIS CREEK MILE 4.15 (STATION 6) DURING MINING AND CONVENTIONAL RECLAMATION, AFTER PARTIAL TREATMENT, DURING REMEDIAL TREATMENT, AND POST RECLAMATION PERIODS

Date	Water temp. C	Turbidity JTU	pH	Total alkalinity $CaCO_3$ mg/l	Total acidity $CaCO_3$ mg/l	Sulfate mg/l	Iron mg/l	Manganese mg/l
During mining and conventional reclamation								
04-13-71	12.8	3	5.4	2	6	26	0.15	0.38
07-07-71	27.8	3	6.8	4	5	-	0.30	1.20
10-04-71	23.3	1	4.0	-	-	95	0.22	2.30
02-09-72	-	-	5.6	-	-	-	-	-
04-18-72	16.7	5	4.7	0	9	35	0.46	1.20
07-25-72	26.9	2	4.5	0	22	160	0.42	4.00
10-25-72	13.0	2	4.1	0	21	110	0.55	3.30
After limited remedial treatment								
08-25-75	23.9	<1	4.8	0	21	150	0.16	4.80
10-30-75	12.2	<1	4.3	0	70	87	0.17	2.30
During remedial treatment								
01-21-76	-	2	5.2	1	9	80	0.90	2.90
04-07-76	12.2	3	4.8	0	14	110	0.74	2.30
07-14-76	20.0	3	5.2	1	14	65	0.67	2.10
10-20-76	8.3	44	4.6	0	22	180	1.70	3.70
04-12-77	13.3	4	4.2	0	14	81	0.42	1.90
07-27-77	21.5	2	4.1	0	18	200	0.34	5.00
10-27-77	12.5	3	5.2	1	6	53	0.37	2.20
Post reclamation								
01-04-78	0.6	6	5.0	0	18	110	0.91	3.20
04-05-78	14.0	6	5.4	9	7	34	0.29	1.30
07-20-78	22.8	5	4.7	0	20	200	0.24	3.80
10-12-78	13.0	<1	5.3	1	9	210	0.13	4.00
01-18-79	3.0	3	4.9	2	19	130	0.70	2.50
04-11-79	12.0	5	4.3	0	12	59	0.62	1.20

TABLE C-6 (continued)

Date	Water temp. C	Turbidity JTU	pH	Total alkalinity $CaCO_3$ mg/l	Total acidity $CaCO_3$ mg/l	Sulfate mg/l	Iron mg/l	Manganese mg/l
07-31-79	22.0	1	4.4	0	29	94	0.22	2.80
10-10-79	9.0	1	4.8	0	<1	150	0.35	3.70
01-24-80	5.0	2	5.0	0	10	55	0.49	0.96
04-21-80	14.0	4	4.8	<1	9	73	0.26	1.40
07-21-80	-	2	4.9	0	6	170	0.13	2.40

TABLE C-7. THE MEAN AND RANGE OF VALUES FOR SELECTED WATER QUALITY PARAMETERS COLLECTED ON OLLIS CREEK RESERVOIR 1 AND 2 FROM AUGUST 1975 TO JULY 1980

		Reservoir 1 OCM 0.78		Reservoir 2 OCM 3.37	
		Surface	20 Feet	Surface	30 Feet
Water temp. C	Mean	14.6	13.1	15.8	11.7
	Range	1.1-30.0	2.0-22.8	1.1-30.0	0.6-22.2
pH	Mean	5.7	5.7	5.1	5.1
	Range	4.4-7.1	4.4-7.0	4.2-6.9	4.2-6.8
Total acidity $CaCO_3$ mg/l	Mean	8.5	12.6	12.9	19.2
	Range	K-80*	K-49	K-130	K-150
Total alkalinity $CaCO_3$ mg/l	Mean	2.6	5.9	0.5	2.1
	Range	0-13	0-47	0-3	0-29
Iron mg/l	Mean	0.36	1.5	0.3	1.6
	Range	0.13-0.77	0.14-14.0	0.08-0.97	0.10-14.0
Manganese mg/l	Mean	1.0	1.3	1.8	2.3
	Range	0.32-2.3	0.40-2.1	0.9-3.2	0.9-3.8
Sulfate mg/l	Mean	60.4	58.0	76.7	83.1
	Range	33-120	20-120	28-180	35-220
Turbidity JTU	Mean	2.7	11.0	3.5	12.9
	Range	K-6	K-70	K-17	1-60

* K indicates a value less than 10.

TABLE C-8. COMPARISON OF WATER QUALITY PARAMETERS FROM STREAMS AFFECTED BY STRIP MINING ON A MINED WATERSHED (OLLIS CREEK) AND AN UNMINED WATERSHED (NO BUSINESS CREEK)

	Mined watershed					Unmined watershed			
Date	pH	Sulfate mg/l	Iron mg/l	Manganese mg/l	Date	pH	Sulfate mg/l	Iron mg/l	Manganese mg/l
- - - - - - - - - Ollis Creek Station 1 - - -					- - - - - - No Business Station 1 - - - -				
01-21-76	5.4	42	0.86	0.98	01-21-76	6.3	4	0.08	0.01
04-07-76	5.2	43	0.43	0.74	04-07-76	5.8	8	0.13	0.03
07-14-76	5.8	54	0.34	0.87	07-14-76	7.0	3	0.07	0.01
10-20-76	5.7	120	0.61	0.62	10-20-76	5.9	4	0.20	0.09
04-12-77	4.8	55	0.14	0.62	04-12-77	5.3	8	0.05	0.02
07-27-77	7.2	96	0.35	1.10	07-27-77	6.8	6	0.07	0.07
10-27-77	5.4	60	0.73	1.20	10-27-77	6.2	7	0.09	0.02
01-04-78	5.1	54	0.37	1.20	01-04-78	5.9	3	0.06	0.10
04-05-78	5.5	31	0.19	1.10	04-05-78	5.4	13	0.21	0.40
07-20-78	6.5	60	0.16	0.11	07-20-78	5.8	3	0.08	0.04
10-12-78	6.8	41	0.15	0.02	10-12-78	7.0	6	0.07	0.04
01-18-79	5.2	50	0.32	0.82	01-18-79	5.7	7	0.05	0.02
04-11-79	4.5	44	0.22	0.86	04-11-79	5.2	2	0.05	0.01
07-31-79	5.5	57	0.24	0.68	07-31-79	5.5	7	0.05	0.04
10-10-79	6.6	77	0.34	0.65	10-10-79	6.2	6	0.05	0.01
01-24-80	5.8	51	0.33	0.86	01-24-80	5.7	6	0.05	0.01
04-21-80	5.6	41	0.09	0.80	04-21-80	5.9	6	0.09	0.04
07-21-80	6.4	42	0.13	0.04	07-21-80	6.9	4	0.05	0.01

TABLE C-8 (continued)

	Mined watershed					Unmined watershed			
Date	pH	Sulfate mg/1	Iron mg/1	Manganese mg/1	Date	pH	Sulfate mg/1	Iron mg/1	Manganese mg/1
- - - - - - - Thompson Creek - - - - - - -					- - - - - - - - No Business Station 3 - - - - - -				
01-21-76	4.7	62	0.23	1.50	02-18-76	5.8	5	-	-
04-07-76	4.5	69	0.28	1.70	04-07-76	6.0	6	-	-
07-14-76	4.8	95	0.30	1.60	07-14-76	7.0	3	0.09	0.10
10-20-76	4.2	140	0.42	2.70	10-20-76	6.0	4	-	-
04-12-77	4.1	110	0.19	1.40	04-12-77	5.2	8	-	-
07-27-77	4.2	60	0.15	1.80	07-27-77	6.8	4	-	-
10-27-77	5.0	47	0.16	0.91	10-27-77	6.2	6	-	-
01-04-78	4.6	80	0.72	2.00	01-04-78	5.8	6	-	-
04-05-78	4.7	66	0.41	2.50	04-05-78	5.8	7	-	-
07-20-78	3.8	130	0.29	2.50	07-20-78	5.5	8	-	-
10-12-78	5.0	110	0.09	3.00	10-12-78	7.4	1	-	-
01-18-79	4.6	96	0.32	2.00	01-18-79	5.6	6	-	-
04-11-79	4.1	46	0.39	0.83	04-11-79	5.3	7	-	-
07-31-79	4.1	79	0.14	2.00	07-31-79	5.5	6	-	-
10-10-79	4.4	120	0.17	3.00	10-10-79	5.9	6	-	-
01-24-80	4.5	48	1.70	0.73	01-24-80	5.6	6	-	-
04-21-80	4.5	49	0.10	0.93	04-21-80	5.8	6	-	-
07-21-80	4.5	83	0.13	1.40	07-21-80	6.8	5	-	-

TABLE C-9. COMPARISON OF WATER QUALITY PARAMETERS FROM STREAMS AFFECTED BY STRIP MINING ON A MINED WATERSHED (OLLIS CREEK) AND AN UNMINED WATERSHED (NO BUSINESS CREEK) USING A PAIRED "t" TEST*

Mined Watershed (Ollis Creek Station 1, U_1)
vs
Unmined Watershed (No Business Creek Station 1, U_2)

Water quality parameter tested

H_o: $U_1 = U_2$, D.F. = 17(18-1), C.I. = 95 percent, T table = 2.110
pH - Calculated "t" = -2.53 ∴ Reject H_o

H_o: $U_1 = U_2$, D.F. = 17(18-1), C.I. = 99 percent, T table = 2.898
Sulfate (SO_4) - Calculated "t" 9.60 ∴ Reject H_o

Iron (Fe) - Calculated "t" = 5.13 - Reject H_o

Manganese (Mn) - Calculated "t" = 8.32 ∴ Reject H_o

Mined Watershed (Thompson Creek Station 8, U_1)
vs
Unmined Watershed (No Business Creek Station 3, U_2)

Water quality parameter tested

H_o: $U_1 = U_2$, D.F = 17(18-1), C.I. = 99 percent, T table = 2.898
pH - Calculated "t" = -12.74 ∴ Reject H_o

Sulfate (SO_4) - Calculated "t" = 10.87 ∴ Reject H_o

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* Data derived from Table C-8. Water quality parameters tested quarterly from 1976 through July 1980.

APPENDIX D

(Supplemental information on macroinvertebrates)

TABLE D-1. TAXA OF MACROINVERTEBRATES COLLECTED QUALITATIVELY AND QUANTITATIVELY DURING STRIP MINING (A), AFTER PARTIAL REMEDIAL TREATMENT (B), DURING REMEDIAL TREATMENT (C), AND AFTER REMEDIAL TREATMENT (D) IN OLLIS CREEK AND ITS TRIBUTARIES

	A 1970-71	B* 8/75-10/75	C 11/75-7/76	C 8/76-10/78	D 1/79-7/80
Platyhelminthes					
Planariidae	X	X	X	-	X
Nematomorpha	X	-	X	-	-
Paragordius sp.	-	-	-	-	X
Nematoda	-	X	-	X	X
Annelida					
Oligochaeta	X	X	X	X	X
Arthropoda					
Crustacea					
Lirceus sp.	X	X	X	X	X
Ascellus sp.	-	-	X	X	X
Gammarus sp.	X	-	-	X	X
Crangonyx sp.	-	-	-	-	X
Cambarus sp.	X	X	X	X	X
Insecta					
Collembola	-	X	X	-	-
Isotomurus sp.	-	-	-	X	X
Smynthurus sp.	-	-	-	X	-
Plecoptera					
Peltoperla sp.	X	X	X	X	X
Brachyptera sp.	-	X	X	-	-
Taeniopteryx sp.	X	-	-	X	-
Nemoura sp.	X	-	X	-	X
Leuctra sp.	-	-	X	X	X
Paraleuctra sp.	X	-	-	-	X
Allocapnia sp.	-	-	-	-	X
Acroneuria sp.	X	X	-	X	X
Isogenus sp.	-	-	-	-	X
Isoperla sp.	X	-	-	-	X
Hastaperla sp.	-	-	X	X	X
Ephemeroptera					
Ameletus sp.	X	-	-	X	X
Siphlonurus sp.	-	-	-	-	X
Isonychia sp.	-	X	-	X	X
Neocloeon sp.	X	-	-	-	-
Centroptilium sp.	X	-	-	-	-
Baetis sp.	X	X	-	X	X
Pseudocloeon sp.	X	-	-	-	X
Cinygma sp.	X	-	-	-	-
Epeorus sp.	X	-	X	X	X
Stenocron sp.	-	-	-	-	X
Stenonema sp.	X	X	X	X	X

TABLE D-1 (continued)

	A 1970-71	B* 8/75-10/75	C 11/75-7/76	C 8/76-10/78	D 1/79-7/80
Heptagenia sp.	-	-	-	-	X
Leptophlebia sp.	-	-	X	-	-
Paraleptophlebia sp.	X	-	-	X	X
Ephemerella sp.	X	-	X	X	X
Tricorythodes sp.	-	-	-	-	X
Caenis sp.	X	-	-	-	-
Ephemera sp.	X	X	X	X	X
Odonata					
Didymops sp.	-	-	-	X	-
Micromia sp.	X	-	-	-	-
Tetragoneuria sp.	X	-	-	X	-
Libullelidae sp.	X	-	-	X	-
Boyeria sp.	X	X	X	-	-
Cordulegaster sp.	-	-	X	-	-
Ophiogomphus sp.	X	-	-	-	-
Gomphus sp.	X	-	-	X	-
Aeschna sp.	X	X	X	-	-
Agrion sp.	X	-	X	X	X
Argia sp.	X	-	-	-	-
Anax sp.	-	-	X	-	-
Ischnura sp.	X	-	-	-	-
Coenagrion sp.	X	-	-	X	-
Hemiptera					
Corixidae	X	X	X	X	-
Notonecta sp.	X	-	-	X	-
Gerris sp.	X	X	X	X	-
Metrobates sp.	-	-	-	-	X
Rhagovelia sp.	X	X	X	X	X
Microvelia sp.	-	X	-	-	X
Megaloptera					
Sialis sp.	X	X	X	X	X
Nigronia sp.	X	X	X	X	X
Corydalus sp.	X	X	X	X	X
Chauloides sp.	-	-	X	-	-
Trichoptera					
Dolophilodes	-	-	X	-	-
Chimarra	X	X	-	X	X
Polycentropus	X	X	X	X	X
Diplectrona	X	X	X	X	X
Cheumatopsyche	X	X	X	X	X
Hydropsyche	X	X	X	X	X
Rhyacophila	-	-	X	X	X
Ptilostomis	-	-	X	X	-
Brachycentrus	-	-	-	X	-
Micrasema	-	-	-	X	-
Pycnopsyche	X	-	X	X	-
Limnephilus	-	-	-	X	-
Neophylax	X	-	-	-	-
Lepidostoma	-	-	X	-	X
Mystacides	X	-	-	-	-

TABLE D-1 (continued)

	A 1970-71	B* 8/75-10/75	C 11/75-7/76	C 8/76-10/78	D 1/79-7/80
Diptera					
Palpomia sp.	X	X	X	X	X
Culicidae	-	-	-	X	-
Dixa sp.	X	-	-	X	-
Chaoborus sp.	-	-	-	-	X
Simulium sp.	X	X	X	X	X
Chironomidae sp.	X	X	X	X	X
Protoplasa sp.	-	-	-	X	-
Tipula sp.	X	X	X	X	X
Pedicia sp.	X	X	X	X	-
Molophilus sp.	-	-	-	-	X
Ormosia sp.	-	-	-	-	X
Pseudolimnophila sp.	-	-	-	X	X
Limnonia sp.	-	-	-	X	-
Hexatoma sp.	X	X	X	X	X
Eriocera sp.	-	X	X	X	-
Antocha sp.	X	-	-	-	X
Dicranota sp.	-	-	-	-	X
Limnophila sp.	X	-	-	-	-
Adelphomyia sp.	X	-	-	-	-
Pilaria sp.	X	-	-	-	-
Atherix sp.	X	-	-	X	-
Chrysops sp.	X	-	-	-	-
Tabanus sp.	X	-	X	X	X
Dolichopodidae	-	-	-	X	-
Empididae	-	X	-	X	X
Lepidoptera					
Pyralidae	-	-	-	X	X
Coleoptera					
Dytiscidae	-	X	-	X	-
Gyrinidae	-	-	X	X	-
Curculionidae	-	-	-	-	X
Dryopidae sp.	-	X	-	X	-
Helichus sp.	X	-	-	-	X
Dineutus sp.	X	-	-	-	-
Bidessus sp.	X	-	-	-	-
Helophorus sp.	X	-	-	-	-
Elmidae	-	X	-	-	-
Stenelmis sp.	X	-	-	X	X
Optioservus sp.	X	-	-	-	-
Hydraenidae	-	-	X	-	-
Hydrophilidae	-	X	-	X	-
Psephenidae					
Psephenus sp.	X	-	-	-	X
Ectoparia sp.	X	-	-	-	-
Mollusca					
Psidium sp.	X	-	X	-	-
Total number of taxa	73	39	49	67	64

* Ollis and Thompson Creeks received some remedial treatment in fall 1974 and spring 1975.

TABLE D-2. NUMBERS OF TAXA, STANDING CROPS (1 FT^2 SURBER) AND DIVERSITY INDICES ($\bar{H}$) FROM OLLIS CREEK (MINED) AND NO BUSINESS CREEK (UNMINED) DURING MINING AND CONVENTIONAL RECLAMATION AND INTENSIVE REMEDIAL TREATMENT

Year	Parameter	Ollis Cr 1 0.68	Ollis Cr 2 1.30	Ollis Cr 3 3.34	Ollis Cr 6 4.15	Laurel Br 4 LBM 0.1	Yellow Br 5 YBM 0.1	Unnamed Trib 7 TM 0.01	Thompson Cr 8 TCM 0.01	No Business Creek 1	No Business Creek 2	No Business Creek 3
1970*	No. of taxa	17.0	†	7.0	4.0	†	†	†	2.0	†	†	†
1971*	No. of taxa	25.0	†	19.0	14.0	34.0	31.0	†	15.0	†	†	†
1975	No. of taxa	20.0	23.0	11.0	19.0	28.0	16.0	12.0	10.0	†	†	†
	No./sq. ft.	13.0	5.0	5.0	7.0	7.0	9.0	2.0	3.0	†	†	†
	$\bar{H}$ diversity	2.5	2.4	1.5	1.9	1.9	1.7	1.4	2.2	†	†	†
1976	No. of taxa	21.0	23.0	16.0	19.0	24.0	16.0	10.0	18.0	42.0	65.0	46.0
	No./sq. ft.	14.0	14.0	7.0	13.0	7.0	8.0	2.0	15.0	58.0	38.0	53.0
	$\bar{H}$ diversity	1.9	1.8	1.9	1.8	1.7	2.0	1.3	1.9	2.9	3.7	3.7
1977	No. of taxa	18.0	23.0	13.0	17.0	29.0	21.0	14.0	18.0	41.0	39.0	51.0
	No./sq. ft.	18.0	11.0	21.0	10.0	13.0	9.0	2.0	18.0	67.0	47.0	64.0
	$\bar{H}$ diversity	2.3	2.1	1.2	2.0	2.4	1.9	1.8	1.9	3.0	3.4	3.7
1978	No. of taxa	19.0	22.0	14.0	15.0	28.0	18.0	8.0	15.0	46.0	49.0	48.0
	No./sq. ft.	11.0	13.0	31.0	14.0	10.0	10.0	3.0	26.0	49.0	78.0	86.0
	$\bar{H}$ diversity	2.1	2.3	1.3	1.9	2.6	2.1	1.1	1.8	3.6	3.3	3.3
1979	No. of taxa	26.0	28.0	18.0	18.0	38.0	24.0	10.0	19.0	40.0	43.0	39.0
	No./sq. ft.	26.0	19.0	21.0	20.1	13.0	10.0	4.0	43.0	46.0	79.0	71.0
	$\bar{H}$ diversity	2.3	2.7	1.4	2.1	3.4	2.5	1.1	1.9	3.3	3.6	3.8
1980	No. of taxa	18.0	19.0	9.0	17.0	28.0	11.0	10.0	15.0	31.0	33.0	36.0
	No./sq. ft.	27.0	9.0	8.0	9.0	13.0	5.0	4.0	29.0	34.0	42.0	48.0
	$\bar{H}$ diversity	1.2	1.5	1.5	2.4	3.2	2.0	1.3	1.6	3.1	3.2	3.1

* Qualitative data from surveillance of Ollis Creek watershed during mining and conventional reclamation.

† Not sampled.

TABLE D-3. COMPARISON OF BENTHIC MACROINVERTEBRATES COLLECTED IN THOMPSON CREEK DURING MINING AND CONVENTIONAL RECLAMATION, REMEDIAL TREATMENT, AND POST REMEDIAL TREATMENT

	During mining and conventional reclamation	During remedial treatment	Post remedial treatment
Annelida			
Oligochaeta	-	X	X
Arthropoda			
Crustacea			
Cambarus sp.	X	X	-
Crangonyx sp.	-	-	X
Insecta			
Plecoptera			
Perlodidae	-	-	X
Peltoperla sp.	X	X	X
Brachyptera sp.	-	X	-
Taeniopterx sp.	-	-	X
Acroneuria sp.	X	X	X
Chloroperla sp.	-	-	X
Leuctra sp.	X	X	X
Ephemeroptera			
Stenonema sp.	-	-	X
Epeorus sp.	X	-	X
Ephemerella sp.	-	-	X
Odonata			
Boyeria sp.	-	X	-
Aeshna sp.	-	X	-
Cordulegaster sp.	-	X	-
Anax sp.	-	X	-
Hemiptera			
Rhagovelia sp.	-	X	X
Corixidae	-	-	X
Gerris sp.	X	X	-
Gyrinus sp.	-	X	-
Megaloptera	X	-	-
Sialis sp.	-	X	X
Nigronia sp.	X	X	X
Corydalus sp.	-	-	X
Trichoptera			
Brachycentrus sp.	-	-	X
Cheumatopsyche sp.	X	-	X
Hydropsyche sp.	-	-	X
Diplectrona sp.	X	X	X
Polycentropus sp.	X	X	X
Pycnopsyche sp.	-	X	X
Lepidostoma sp.	-	X	-
Lepidoptera	-	-	X
Diptera			

TABLE D-3 (continued)

	During mining and conventional reclamation	During remedial treatment	Post remedial treatment
Ceratopogonidae	-	-	X
Dixidae	-	-	X
Dolichopodidae	-	-	X
Tabanidae	-	X	-
Eriocera sp.	-	X	-
Hexatoma sp.	X	-	X
Pseudolimnophila sp.	-	-	X
Simuliidae	-	X	X
Chironomidae	X	X	X
Empididae	-	X	X
Coleoptera			
Curculionidae	-	-	X
Dytiscidae	-	X	X
Hydrophilidae	-	X	-
Total number taxa	13	26	33

TABLE D-4. MEANS AND RANGES OF BENTHIC MACROINVERTEBRATE NUMBERS FROM OLLIS CREEK AND ITS TRIBUTARIES AFTER LIMITED REMEDIAL TREATMENT, DURING REMEDIAL, AND POST REMEDIAL TREATMENT

	After limited remedial treatment 8/75-10/75		During remedial treatment 11/75-7/76		During remedial treatment 8/76-10/78		Postremedial treatment 1/79-7/80	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
OCM 0.68	20.25	4.25-45.50	4.00	1.50-14.00	19.75	1.00-56.00	26.42	4.00-74.00
OCM 1.30	14.90	0.75-25.00	2.75	0.25-7.00	18.75	2.00-74.00	14.28	3.00-35.00
OCM 3.34	14.10	2.75-31.75	2.60	1.00-4.50	22.16	3.00-78.00	15.42	4.00-31.00
OCM 4.15	10.00	2.75-22.50	3.40	0.25-11.25	18.00	2.00-32.00	15.14	4.00-46.00
Laurel Branch	3.10*	1.00-6.00	3.10*	0.25-7.00	12.00	4.00-32.00	12.57	6.00-22.00
Yellow Branch	10.75	7.25-22.25	3.60	0.75-8.50	11.25	1.00-24.00	7.43	5.00-17.00
Unnamed Tributary	1.40	1.25-1.50	1.00	0-2.50	2.66	1.00-7.00	4.14	1.00-7.00
Thompson Creek	1.50†	1.50	8.50	2.00-35.50	22.25	6.00-51.00	37.00	17.00-79.00

* No reclamation yet done.

† Only one month sampled after limited remedial treatment.

TABLE D-5. MEANS AND RANGES OF THE NUMBER OF TAXA TAKEN IN EACH AQUATIC MACROINVERTEBRATE SAMPLE FROM OLLIS CREEK AND ITS TRIBUTARIES DURING AND AFTER INTENSIVE REMEDIAL TREATMENT

	During remedial treatment		During remedial treatment		Post remedial treatment	
	Aug 1975	Jul 1976	Aug 1976	Oct 1978	Jan 1979	Jul 1980
	Mean	Range	Mean	Range	Mean	Range
Ollis Creek mile 0.68	6	0-16	9	3-14	10	3-22
Ollis Creek mile 1.30	5	1-16	9	4-18	10	4-20
Ollis Creek mile 3.34	4	3-7	6	1-11	7	4-12
Ollis Creek mile 4.15	5	1-10	8	4-13	10	4-14
Laurel Branch 0.10	5	1-13	10	5-18	16	11-26
Yellow Branch 0.13	5	2-10	8	2-14	8	3-18
Unnamed Tributary 0.01	3	0-6	3	0-6	4	2-9
Thompson Creek 0.01	7	4-13	8	5-16	9	5-13
	13 sample dates		12 sample dates		7 sample dates	

TABLE D-6. TAXA OF MACROINVERTEBRATES COLLECTED QUALITATIVELY AND QUANTITATIVELY FROM MARCH TO SEPTEMBER 1977 IN OLLIS CREEK RESERVOIR 1

Taxa

- Nematomorpha
  - Paragordius sp.

- Annelida
  - Oligochaeta

- Arthropoda
  - Crustacea
    - *Ascellus* sp.
    - *Cambarus* *bartonii*

- Insecta
  - Ephemeroptera
    - *Hexagenia* *bilobata*
    - *Pseudocleon* sp.
    - *Baetis* sp.
  - Odonata
    - *Enallagma* *divagans*
    - *Libellula* *forensis*
    - *Gomphus* *vastus*
    - *Tetragoneuria* *cynosura*
    - *Plathemis* *lydia*
  - Hemiptera
    - *Palmacorixa* sp.
    - *Gerris* sp.
  - Megaloptera
    - *Nigronia* *fasciatus*
    - *Sialis* sp.
  - Trichoptera
    - *Ptilostomus*
    - *Oecetis* sp. cf. *inconspicuous*
    - *Phylocentropus* *placidus*
    - *Pycnopsyche* *guttifer*

TABLE D-6 (continued)

Taxa
Diptera
Chironomidae
Clinotanypus sp.
Coelotanypus scapularis
Ablabesmyia tarella
Procladius sp.
Tribelos jucundus
Parachironomus alatus
Stenochironomous sp.
Polypedilum halterale
Tabanidae
Chrysops sp.
Tabanus trepidus
Certatopogonidae
Palpomyia tibalis
Empididae
Chelifera sp.
Chrysomelidae
Tipulidae
Eriocera sp.
Limnophora discreta
Culicoides sp.
Chaoborus sp.
Dixidae
Rhagionidae
Coleoptera
Dineutus sp.
Hydroporus carolinea
Galerucella nymphaea
Mollusca
Pelecypoda
Spaerium sp.

TABLE D-7. STATISTICAL COMPARISON OF BOTTOM FAUNA STANDING CROPS (NUMBER PER SQUARE FOOT) AND NUMBER OF TAXA AT SELECTED STATIONS IN OLLIS AND NO BUSINESS CREEK

Mined Watershed (Ollis Creek Station 1, U_1)
vs
Unmined Watershed (No Business Creek Station 1, U_2)

Benthic parameter tested

H_o: $U_1 = U_2$, D.F. = 17(18-1) C.I. 99 percent, T table = 2.898
Total Taxa - Calculated "t" = -8.58 ∴ Reject H_o

H_o: $U_1 = U_2$, D.F. = 17(18-1) C.I. 99 percent, T table = 2.898
Mean Numbers per foot square - Calculated "t" = -4.21 ∴ Reject H_o

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Mined Watershed (Thompson Creek Station 8, U_1)
vs
Unmined Watershed (No Business Creek Station 3, U_2)

Benthic parameter tested

H_o: $U_1 = U_2$, D.F. = 17(18-1) C.I. 99 percent, T table = 2.898
Total Taxa - Calculated "t" = -19.40 ∴ Reject H_o

H_o: $U_1 = U_2$, D.F. = 17(18-1) C.I. 99 percent, T table = 2.898
Mean Numbers per foot square - Calculated "t" = -4.81 ∴ Reject H_o

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* Data derived from Table D-2.

TABLE D-8. A SUMMARY COMPARISON OF NUMBERS OF TAXA, STANDING CROP, AND DIVERSITY INDICES FROM OLLIS CREEK PROPER, ITS TRIBUTARIES, AND NO BUSINESS CREEK DURING MINING AND CONVENTIONAL RECLAMATION AND AFTER INTENSIVE REMEDIAL LAND TREATMENT

	1970*	1971*	1975			1976			1977			1978			1979			1980		
	No. of taxa	No. of taxa	No. of taxa	No. per ft^2	$\bar{H}$ div	No. of taxa	No. per ft^2	$\bar{H}$ div	No. of taxa	No. per ft^2	$\bar{H}$ div	No. of taxa	No. per ft^2	$\bar{H}$ div	No. of taxa	No. per ft^2	$\bar{H}$ div	No. of taxa	No. per ft^2	$\bar{H}$ div
Tributaries	2†	27	17	5	1.8	31	8	1.7	21	11	2.0	17	15	1.9	23	18	2.2	16	13	2.0
Ollis Creek	9	19	18	8	2.1	27	12	1.9	18	15	1.9	18	17	1.9	23	21	2.1	16	13	1.7
No Business Creek	— NOT ---- SAMPLED ----					58	50	3.4	44	59	3.4	49	71	3.4	61	65	3.6	-	41	3.2

* Qualitative data from surveillance of Ollis Creek watershed during mining and conventional reclamation.

† Only one station sampled (Thompson Creek).

APPENDIX E

(Supplemental information on fish)

TABLE E-1. FISH COLLECTED FROM OLLIS CREEK AND TRIBUTARIES DURING 1970-1971 AND 1975-1980

Common name	Scientific name	1970-71	1975-76	1977-78	1979-80
Stoneroller	*Campostoma anomalum*	X			
Emerald shiner	*Notropis atherinoides*	X	X		
Minnow	*Pimephales* sp.	X			
Creek chub	*Semotilus atromaculatus*	X	X	X	X
White sucker	*Catostomus commersoni*	X	X		
Bluegill	*Lepomis macrochirus*	X	X		
White crappie	*Pomoxis annularis*			X	
Darter	*Etheostoma* sp.	X			
Northern hog sucker	*Hypentelium nigricans*				X

TABLE E-2. NUMBERS AND WEIGHTS OF FISH COLLECTED QUARTERLY IN OLLIS CREEK FROM DECEMBER 1976 THROUGH JULY 1980

	12-76	4-77	7-77	10-77	1-78	4-78	7-78	10-78	1-79	4-79	8-79	10-79	1-80	4-80	7-80
Station 1 OCM 0.78															
Bluegill	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Creek chub	-	-	-	-	*	-	-	-	*	-	2.0	-	*	-	8.0
Total weight (g)	3.0	-	-	-	*	-	-	-	*	-	3.7	-	*	-	42.8
Station 2 OCM 1.3															
Creek chub	-	-	-	-	*	-	-	-	*	-	8.0	-	*	-	-
Northern hog sucker	-	-	-	-	*	-	-	-	*	-	-	1.0	*	-	-
Total weight (g)	-	-	-	-	*	-	-	-	*	-	3.3	2.5	*	-	-
Station 3 OCM 3.34															
White sucker	5.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Emerald shiners	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Creek chub	2.0	-	-	-	*	-	-	-	*	-	-	-	*	-	3.0
Total weight (g)	52.0	-	-	-	*	-	-	-	*	-	-	-	*	-	3.0
Station 4 Laurel Branch LBM 0.1															
Creek chub	-	-	-	-	*	3.0	-	-	*	4.0	5.0	-	*	2.0	2.0
Total weight (g)	-	-	-	-	*	-	-	-	*	4.0	3.8	-	*	2.5	1.5
Station 5 Yellow Branch YBM 0.1															
No fish taken for all dates	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE E-2 (continued)

	12-76	4-77	7-77	10-77	1-78	4-78	7-78	10-78	1-79	4-79	8-79	10-79	1-80	4-80	7-80
Station 6 OCM 4.15															
Creek chub	-	-	-	-	*	1.0	-	-	*	-	-	-	*	-	-
Station 7 Unnamed Tributary RM 0.1															
No fish taken for all dates	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Station 8 Thompson Creek TCM .01															
No fish taken for all dates	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Not sampled.

TABLE E-3. FISH SPECIES COLLECTED DURING 1975-1980 IN OLLIS CREEK AND NO BUSINESS CREEK

Common name	Scientific name	Ollis Creek	No Business Creek
Stoneroller	*Campostoma anomalum*		X
Emerald shiner	*Notropis atherinoides*	X	
Bluntnose minnow	*Pimephales notatus*		X
Blacknose dace	*Rhinichthys atratulus*		X
Creek chub	*Semotilus atromaculatus*	X	X
White sucker	*Catostomus commersoni*	X	X
Northern hog sucker	*Hypentelium nigricans*	X	X
Bluegill	*Lepomis macrochirus*	X	
White Crappie	*Pomoxis annularis*	X	
Stripetail darter	*Etheostoma kennicotti*		X
Arrow darter	*Etheostoma sagitta*		X

TABLE E-4. NUMBERS AND WEIGHTS OF FISH COLLECTED BY ELECTROFISHING FROM NO BUSINESS CREEK
NOVEMBER 1975 THROUGH JULY 1980

	11/75	1/76	4/76	8/76	11/76	8/77	10/77	7/78	10/78	1/79	4/79	7/79	10/79	1/80	4/80	7/80
Station 1																
Northern hog sucker	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Creek chub	11	15	6	3	2	4	2	12	21	3	14	5	4	1	10	8
Bluntnose minnow	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stoneroller	4	5	-	-	-	1	-	1	-	2	-	-	-	-	-	1
Blacknose dace	1	-	-	-	-	-	-	6	-	-	-	-	1	3	7	3
Arrow darter	1	2	-	-	-	3	-	-	1	-	-	-	1	-	-	-
Stripetail darter	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-
Total weight in grams	104	48	79	3	8	32	-	61	53	10	65	20	83	6	88	79
Station 2																
Northern hog sucker	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
White sucker	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Creek chub	-	6	-	9	7	6	11	8	15	15	11	11	-	-	-	-
Bluntnose minnow	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stoneroller	-	-	-	-	-	-	-	-	-	-	-	-	NOT SAMPLED			
Blacknose dace	-	-	-	-	-	2	-	2	-	-	-	1	-	-	-	-
Arrow darter	-	1	3	-	-	-	1	1	-	-	-	-	-	-	-	-
Stripetail darter	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Total weight in grams	-	74	51	36	74	45	-	66	170	145	155	127	-	-	-	-

TABLE E-4 (continued)

	11/75	1/76	4/76	8/76	11/76	8/77	10/77	7/78	10/78	1/79	4/79	7/79	10/79	1/80	4/80	7/80
Station 3																
Northern hog sucker	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Creek chub	-	1	6	3	4	4	10	7	17	6	5	10	-	-	-	-
Bluntnose minnow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stoneroller	-	-	-	-	-	-	-	-	-	-	-	-	NOT SAMPLED			
Blacknose dace	-	2	-	2	1	-	5	-	-	1	2	4	-	-	-	-
Arrow darter	-	2	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Stripetail darter	-	-	-	1	-	3	-	-	-	-	-	-	-	-	-	-
Total weight in grams	-	16	80	114	28	24	-	35	109	53	8	70	-	-	-	-